ISRAEL'S TECHNOLOGY SECTOR

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PREFACE

This study provides a general assessment of the science and technology (S&T) and research and development (R&D) landscape in Israel, one of the world's most prolific innovators in advanced technologies, particularly information and communication technology (ICT). Israel is widely seen as Silicon Valley–like, and perhaps second only to Silicon Valley as an exemplification of the phenomenon of a start-up–intensive, entrepreneurship-led "high-tech cluster."

The report is organized in four major sections. The first, an introductory section, summarizes the factors that account for the "takeoff" of the Israeli high-tech cluster in the early 1990s and for its continued flourishing. The second section presents the key indicators of Israel's strengths as an R&D-based innovating economy, including "input" indicators, such as R&D expenditures and human capital, and "output" indicators, including patents, publications, the number of high-tech start-ups, and the contribution of high-tech products and high-tech exports to the overall Israeli economy. The third section focuses on government policy decisions and actions that have played a crucial role in Israel's emergence and current standing as a high-tech powerhouse. The fourth section discusses Israel's achievements and trends in the country's key technology sectors and emerging sectors: information and communication technologies; biotechnology; nanotechnology; "cleantech," or environmental technologies; military technologies; aerospace; and unconventional weapons.

The report concludes that the Israeli high-tech cluster is thriving, despite the global implosion of ICT in the early twenty-first century, and notwithstanding Israel's persistent security problems. Israel's high-tech cluster seems to be resilient, in part because of the benefits that the presence of other firms, by definition, bestows on the individual firms within the cluster. In addition, Israel's high-tech industry is reasonably diversified, and growing more so, thanks in part to deliberate government actions to foster renewal forces within the cluster.

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KEY FINDINGS

- Israel, a country of about 7 million people with a gross domestic product (GDP) of about US$140 billion, contributes disproportionately to the world's innovation in a broad range of science and technology (S&T) fields.
- Israel is one of the most prolific centers of high-technology innovation in the world. Many see Israel as second only to Silicon Valley in exemplifying the phenomenon of a high-tech cluster, specifically, an entrepreneurship-led cluster. As defined by the U.S. Department of Commerce in 1997, such economic clusters are regional agglomerations of interrelated industries in which the concentration of firms produces benefits for each particular firm. The technological composition of Israeli innovations matches worldwide technological trends—reflecting, in part, the fact that Israeli high technology is heavily export-oriented.
- As in the Silicon Valley cluster, Israel's technology sector is based on start-up companies, whose proliferation has spawned a financial community of venture-capital (VC) firms to invest in start-ups. Israel has more companies listed on the U.S. stock exchanges than any other country, except the United States and Canada. Israeli companies in many fields are typically small, with fewer than 20 employees.
- The core of the Israeli technology cluster remains the information and communication technology (ICT) that originally fueled the emergence of the cluster in the 1990s: hardware design, computer software, data communications, electro-optics, and network/Internet security. Related important high-tech industries in Israel include military technology and avionics.
- Israeli's high-tech sector is diversifying, with greater focus on life sciences industries, especially biotechnology and agrobiotechnology. In the last decade, biotechnology has been designated a national priority. On various measures of activity in biotechnology, Israel ranks among mid-sized West European countries, such as Belgium.
- Within biotechnology, Israel is at the forefront of the field of stem-cell research. In 2006 Israeli researchers ranked in second place after the United States in absolute numbers of peer-reviewed scientific publications in the field. Israeli stem-cell researchers do not face restrictions based on religious grounds, except for a ban on human cloning.
- Emerging sectors in Israel also include nanotechnology and "cleantech," technologies for resource preservation and environmental cleanup. Israel has long been an innovator in water technologies—drip irrigation and recycling—and in solar energy. Israel invented drip irrigation and boasts the world's largest desalination facility. The government has recently stepped up support programs in the water and renewable energy fields.
- Specific national government policy decisions involving research and development (R&D) in S&T are key factors in the emergence and continued flourishing of Israel's high-tech cluster. Israel pursues an industrial policy in which R&D-based, product-oriented innovation and entrepreneurship are seen as central to economic development. The government offers various kinds of support, not only for R&D in the business sector but also for the creation of new businesses.

- As early as the late 1960s, the government recognized that Israel's comparative advantage lay in its high-quality human capital and advanced R&D capabilities in S&T. These assets historically emanated from two sources: Israel's world-class academic institutions and the military's computer training and high-tech R&D units. Israel's explicit policy, reaffirmed and strengthened over the years, has been to leverage and diffuse its preexisting R&D prowess into the civilian commercial sector in order to realize greater returns from R&D for the entire economy.

- The Office of the Chief Scientist (OCS) of the Ministry of Industry, Trade, and Labor (MITL), established to implement the government's industrial policy, not only backs civilian/commercial research programs but also positively encourages the development of high-tech start-up companies, allowing them to set their R&D agenda. The OCS operates programs that support civilian/commercial-sector innovation through R&D grants for product development, technology incubators, academia-to-industry technology-transfer units, and numerous international R&D cooperation agreements.

- With the Israeli government's encouragement, international technology giants continue to establish or to expand product development centers in Israel. Beginning in the 1980s, the government provided incentives—e.g., grants and tax breaks—to companies that located their R&D centers in Israel. Incentives were not provided to locate lower-skilled high-technology manufacturing operations in Israel.

- Recognizing Israel's R&D and human capital advantages, numerous leading U.S. technology firms or multinational enterprises, such as Cisco, Intel, and Lucent, have sited their core R&D functions in Israel, either by establishing R&D units there or by acquiring and transforming Israeli start-ups.

- Policies of the Israeli state have also propelled the Israeli high-tech sector to its intimate relationship with the U.S. financial world and high-tech industrial sector. In many ways, the Israeli high-tech cluster is an integral part or extension of the U.S. high-tech sector.

- This close relationship with the United States has enabled Israelis to identify gaps in the U.S. high-tech market and to develop innovative niche market products, for example, Internet firewalls, instant messaging, and data storage media such as flash drives.

- Israel's high-tech sector is very attractive to international investors, who typically buy stock in Israel's publicly listed companies or participate in direct buyouts of Israeli companies. Israeli technology companies raise capital on various stock markets, with most listing in the United States. Most VC funding for Israeli companies comes from the United States.

- Israel has many R&D collaborations with foreign partners. Although the United States remains by far its largest partner, Israel in recent years has diversified its cooperation to include Europe, India, and Singapore.

- In the area of military technology, Israel is a major world exporter, with strengths in unmanned weapons technology, missiles, and small satellites, as well as state-of-the-art small arms. In exchange for a high level of U.S. military support, Israel is obliged to buy the major part of its military equipment from the United States. Since sales to its own domestic market are thus constrained, Israel's own large defense industry is dependent on exports. Conflicts

between the United States and Israel periodically arise over Israel's plans to share military technologies with other countries, for example, recently, China.

- Currently, as in earlier decades, Israeli policymakers are anxious to foster the ability of researchers to commercialize their research breakthroughs through the development of cutting-edge products. As in the past, Israelis hope to succeed with the kinds of niche products developed by Israeli ICT for the Internet and personal computers, e.g., the instant messaging service sold to America Online, flash disk technology, and Voice Over Internet Protocol.

- The very nature of Israel as a high-tech cluster bestows upon it "agglomeration benefits" that make likely the country's continuing strength as an innovator in ICT. At the same time, the "cluster benefits" produced by the concentration of firms—concentrated technical skills, capital availability, business mentoring, and specialized services—are a likely source of resilience that will also conduce to Israel's innovative success in new fields.

- New fields in which Israel currently holds an edge globally include stem-cell research, certain water technologies, including desalination, and solar-energy technologies. In stem-cell research, as in other biotech research on therapies, the challenge is to move promising therapies through the numerous testing phases to a saleable product. Israel's small size could limit its success in such a resource-intensive enterprise. In water and solar technologies, Israel's headstart could evaporate, when other countries get more serious about resource alternatives. Both the government and the private sector in Israel continually bear such risks in mind.

INTRODUCTION

A general assessment of the science and technology (S&T) and research and development (R&D) landscape in Israel reveals the country to be one of the world's most prolific innovators in advanced technologies, and a powerhouse of high-tech–based entrepreneurial activity. In particular, during the 1990s and beyond, Israel has seen a spectacular rate of expansion and entrepreneurship in a key sector of global growth, information and communication technology (ICT). In recent years, Israeli researchers and entrepreneurs have also significantly expanded their efforts beyond ICT, in part with government support, into other high-tech sectors such as biotechnology, nanotechnology, and environmental technologies. In addition, Israel continues to maintain its long-standing strength in cutting-edge military technologies and niche areas of aerospace.

In view of Israel's strongly innovative and entrepreneurial character, the country is widely seen as one of the few Silicon Valley–like technology centers in the world.[1] Indeed, thanks to Israel's rapid growth in ICT activities and entrepreneurship during the 1990s, Israel is often considered second only to Silicon Valley as an exemplification of the phenomenon of a "high-tech cluster."[2] Clusters—also variously called industrial clusters, business clusters, and regional clusters—have been analyzed in the literature of economic innovation and development since at least the time of Silicon Valley's emergence as an engine of economic growth. As the U.S. Department of Commerce characterized such clusters in 1997, they are regional agglomerations of interrelated industries in which the concentration of firms produces benefits for each particular firm.[3] In the case of the Israeli ICT-based cluster, the concentration of firms arose through the proliferation of entrepreneurial start-ups. The positive "agglomeration effects" that the presence of numerous other firms generates for Israel's individual companies typify the benefits that clusters provide. The benefits that Israel enjoys include, for example, strong

[1] Manuel Trajtenberg, "Innovation in Israel, 1968-97: A Comparative Analysis Using Patent Data," NBER Working Paper No. W7022 (March 1999), http://ssrn.com/abstract=155849.
[2] On high-tech clusters, see Timothy F. Bresnahan and Alfonso Gambardella, *Building High-Tech Clusters: Silicon Valley and Beyond* (Cambridge: Cambridge University Press, 2004). On Israel as a high-tech cluster, see Catherine de Fontenay and Erran Carmel, "Israel's Silicon Wadi: The Forces Behind Cluster Formation," in *Building High-Tech Clusters: Silicon Valley and Beyond*, ed. Timothy F. Bresnahan and Alfonso Gambardella, 40–77 (Cambridge: Cambridge University Press, 2004).
[3] Timothy F. Bresnahan, Alfonso Gambardella, and AnnaLee Saxenian. "Old Economy Inputs for New Economy Outputs: Cluster Formation in the New Silicon Valleys," *Industrial Corporate Change* 10, no. 4 (2001): 835–60 (via Proquest).

common buyer–supplier linkages, technology spillovers, shared research facilities for cutting-edge technologies, an enhanced technical skill base, venture-capital (VC) availability, entrepreneurship mentoring, and a common foundation of specialized economic institutions and service providers.[4] Such cluster effects have boosted the viability of Israel's individual firms and their ability to generate innovative, market-focused products. In turn, the cluster-generated performance boost for the individual companies has accelerated the growth rate of the overall economy. Israel's ICT innovation and entrepreneurship have been the main engines of Israel's strong economic growth in the 1990s and beyond, as ICT products have contributed an ever-rising percentage of Israel's exports.[5]

Even with the bursting of the high-tech bubble in 2000, Israel managed to retain and build upon its preeminence in high technology. Israel's cluster of innovative activity is now diversifying beyond ICT into other high-tech fields such as biotechnology and is broadening its international linkages beyond its U.S ties.[6]

In seeking to account for the unanticipated "takeoff" of Israel's ICT-led entrepreneurial cluster in the early 1990s, analysts are in broad agreement as to major contributing factors, if not the weight that each factor should be assigned.[7] All lists of the critical ingredients for Israel's emergence as such a cluster highlight one particular factor, Israel's long-term investment in the education of a skilled labor force and, especially, a workforce with strong R&D capabilities in S&T. When Israel emerged as a start-up–intensive high-tech cluster, it effected a transformation from a primarily agriculture-based economy with a large farm export sector and some military-dominated industries.[8] However, unlike other economies starting at a similar developmental level, Israel was already well endowed with a strong technical skill base and sophisticated and extensive R&D capabilities.[9]

One source of these human-capital and research assets was Israel's world-class academic resources. From early in its history, Israel established itself as a powerhouse for basic scientific

[4] Bresnahan and Gambardella, *Building High-Tech Clusters*, 331–37.
[5] Manuel Trajtenberg, "Innovation Policy for Development" (paper presented at Mt. Veritas Conference, June 2007), 22, http://etp-monteverita.epfl.ch/webdav/site/etpmonteverita/shared/presentations/Trajtenberg_presentation MV.ppt.
[6] Bresnahan, Gambardella, and Saxenian. "Old Economy Inputs for New Economy Outputs."
[7] Bresnahan, Gambardella, and Saxenian. "Old Economy Inputs for New Economy Outputs."
[8] Bernard Kahane and Tzvi Raz, "Innovation Projects in Israeli Incubators: Categorization and Analysis," *European Journal of Innovation Management* 8, no.1 (January 10, 2005): 91–106 (via Proquest).
[9] Dan Breznitz, "An Iron Cage or the Final Stage? Intensive Product R&D and the Evolution of the Israeli Software Industry," *Research Policy*, 2005, http://ssrn.com/abstract=753486.

research and has established research institutions that are on a par with some of the world's strongest research universities. Three major Israeli academic institutions, the Weizmann Institute of Science, the Israel Institute of Technology (the Technion), and the Hebrew University, antedated Israel's founding as a state, while four others were established later, providing a substantial scientific and technological infrastructure for a country of Israel's size.[10]

A second source of Israel's strong technical skill base and R&D prowess is technical training provided in the military. The Israeli military has made a practice of deploying the technically gifted among its conscript force in ways that nurture their technical competencies and connections. In particular, the military has long provided selected trainees with sophisticated computer-related capabilities relevant to ICT, the very area in which civilian market opportunities beckoned in the early 1990s.

Another key factor in the emergence of Israel's high-tech cluster was a conjuncture of events that rendered Israel's technically skilled labor force underemployed just as market demand for civilian ICT products was about to explode. In the late 1980s and early 1990s, as the Cold War was ending and the global weapons market shrank, military industries laid off hundreds of Israeli engineers and technicians who had worked on sophisticated weapons systems.[11] The resulting labor market oversupply of high-level skills was exacerbated by the arrival of 1 million ex-Soviet citizens with an above-average education.[12] Fortunately for the underemployed and for Israel, technological opportunity in the form of burgeoning demand for innovative civilian high-tech products awaited those who could think in an entrepreneurial fashion about how to refocus their expertise outside the military sphere. Success in the civilian economy would be a matter of exploiting the growing demand—especially the expanded demand for ICT products that accompanied the commercialization of the Internet—through the invention of niche products, e.g., network-security products that complemented the products of the world's main high-tech centers, chiefly the United States. Israelis had the advantage, in seeking to meet this demand, of privileged linkages to the demand's main source, the United States.

[10] European Community Research and Development Information Service (CORDIS), *ERAWATCH Research Inventory Report: Israel*, 2006, http://cordis.europa.eu/erawatch/index.cfm?fuseaction=ri.content&topicID=373&countryCode=IL&parentID=4. Hereafter cited as *ERAWATCH*.
[11] Dan Breznitz, "Collaborative Public Space in a National Innovation System: A Case Study of the Israeli Military's Impact on the Software Industry," *Industry and Innovation* 12, no. 1 (March 2005): 31–64.
[12] Breznitz, "Collaborative Public Space."

A further crucial factor in Israel's takeoff into cluster growth, in addition to a strong but underutilized skill base and exploitable technological opportunity, was the government's long-standing decision to play an activist role in the economy.[13] As early as the late 1960s, the government had adopted an S&T-focused industrial policy with a stated aim to realize greater returns to the economy from Israel's preexisting high skill base and prowess in R&D. Predicated on Israel's recognition that its comparative advantage lay in its human resource and R&D assets, the policy called for leveraging these assets through the rapid commercialization of innovative ideas and the creation of innovation-based industries.[14] Through the early 1990s, Israel implemented the policy mainly through grants to R&D-performing firms for the early-stage development of new technology products. The grants, a substitute for unavailable private capital, were given under loan conditions, with payback conditional on success. The government also encouraged the world's major high-tech multinational companies (MNCs), starting with Intel, Motorola, and IBM, to locate their R&D centers in Israel to take advantage of Israel's R&D assets. In the early 1990s, after numerous MNCs had indeed set up R&D affiliates in Israel, the government further stepped up its support to its own indigenous companies by establishing technology incubators to improve the management skills in entrepreneurial start-ups and thus their survival and growth prospects. The government also played an active role in initiating a VC industry in Israel to finance the later-stage development of technological products.[15]

Another critical factor in Israel's emergence as a high-tech cluster—a factor that Israeli government actions reinforced in a variety of ways—was the country's intimate relationship with the United States. This relationship gave Israel privileged access not only to the most important product market for Israel's niche products but also to skills that were missing locally, such as the marketing know-how to penetrate global markets with ICT products. Close contacts with the United States have had financial benefits for Israel. Israel has been the largest annual recipient of U.S. international aid since 1976 and readily gained access to U.S. capital markets.[16] Israel adopted the U.S. model for VC and start-up interactions and has derived most of its venture

[13] Sunil Mani, *Government, Innovation and Technology Policy: An International Comparative Analysis* (Maastricht, Netherlands: New Horizons in the Economics of Innovation Series, December 2002), 5.
[14] Manuel Trajtenberg, "R&D Policy in Israel: An Overview and Reassessment," *NBER Working Paper Series*. Working Paper 7930 (October 2000): 5, http://www.nber.org/papers/w7930.
[15] Gil Avnimelech and Morris Teubal, "VC-Start-up Co-Evolution and the Emergence and Development of Israeli New High-Tech Cluster," *Economics of Innovation and New Technology* 13, no. 1 (2004): 33-60 (via Proquest).
[16] Carol Migdalovitz, "Israel: Background and Relations with the United States," *CRS Issue Brief for Congress,* IB82008, updated May 18, 2006, 2, http://www.au.af.mil/au/awc/awcgate/crs/ib82008.pdf.

funding from U.S. investors. When Israeli start-ups reached the stage that they required greater capital resources than VC funds could provide, the start-ups listed on public stock exchanges, choosing by preference the U.S. stock exchange. Alternatively, the start-ups were bought outright in merger and acquisition (M&A) deals—deals most often struck with U.S. companies or U.S.-based multinationals.[17] In effect, one of the most prized Israeli products for the U.S. market consisted of Israel's own high-tech companies.

Israel's ICT-led cluster of entrepreneurship and innovation has proven resilient enough to weather the high-tech downturn starting in 2000, as well as several flare-ups of the Israeli–Palestinian conflict. Although the cluster has been compelled to adjust somewhat the composition of its activities, focusing less exclusively on ICT, its firms collectively continue to deliver strong, export-led growth in high technology, providing most of the growth to Israel's entire economy.[18] Israel's accomplishments at the cutting-edge of R&D-based S&T remain exceptional according to a majority of market indicators.

KEY INDICATORS OF R&D INTENSITY AND S&T PERFORMANCE

Israel's R&D intensity in S&T fields, as well as the country's S&T performance relative to others, are subject to measurement by various internationally established sets of indicators. Commonly used assessment systems include the Organisation for Economic Co-operation and Development Science and Technology Indicators (OECD STI) Scoreboard, the European Commission European Research Area Science and Technology Indicators (ERA–STI) Key Figures, and the U.S. National Science Foundation Science and Engineering (NSF S&E) Indicators. These systems typically provide benchmark data both on a country's inputs to its R&D and S&T activities and on outputs from the activities. R&D inputs include the level of national investment or expenditure on R&D and human resources, e.g., personnel availability and training. Output measures typically include patents and scientific publications but also may include data on R&D-based business achievements, such as the number of start-up companies, the availability of venture capital, the listing of companies on stock exxchanges, and the level of

[17] Joan Harrison, "Israel's High-Tech Sector Continues to Rack Up Deals," *Mergers and Acquisitions* 42, no. 6 (June 2007): 14-19 (via Proquest).
[18] Trajtenberg, "Innovation Policy for Development," 22.

high-tech exports. These various kinds of indicators are potentially useful for, among other things, the setting of priorities in national policy making.

Resources Allocated to R&D Efforts

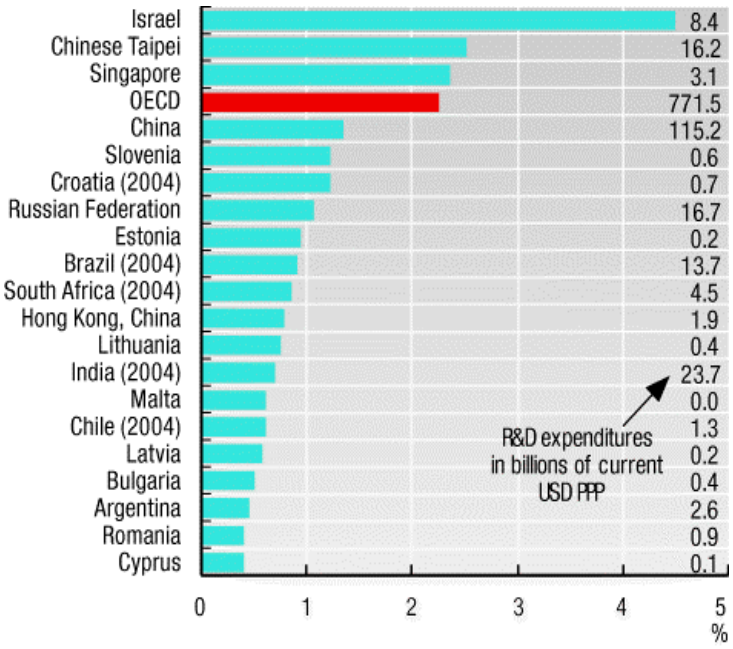
The resources allocated to Israel's R&D efforts—the inputs—are measured using two indicators, R&D-related expenditures and human capital, including personnel availability and characteristics.

National Expenditures on R&D

Compared to other countries, Israel's national annual R&D spending— gross domestic expenditure on R&D (GERD)—is exceptionally high.[19] When measured by the main aggregate used for international comparisons, R&D spending per unit of gross domestic product (GDP), Israel ranks number one in the world.[20] In 2006 Israel's GDP was US$140.5 billion and its spending on civilian R&D expenditure as a percentage of GDP, or R&D intensity, amounted to 4.8 percent of GDP, compared to 2.8 percent in the United States.[21] Israel's spending in 2005 was twice the OECD average of 2.2 percent. That percentage placed Israel, a non-OECD economy, well ahead of Taiwan and Singapore, the only other non-OECD economies with R&D intensity exceeding the OECD average (see figure 1).[22] Israel's R&D intensity in 2005 also exceeded that of, in order, Sweden, Finland, and Japan, the only three OECD countries in which the R&D-to-GDP ratio exceeded 3 percent.[23]

[19] For comprehensive coverage of Israeli data on R&D-related topics, see Israel, Central Bureau of Statistics (CBS), *National Expenditure on Civilian Research and Development, 1989–2004* (Jerusalem: State of Israel, Central Bureau of Statistics, revised data from December 12, 2007), http://www.cbs.gov.il/mop/mop_2004/mop04eng.htm.
[20] Organisation for Economic Co-operation and Development (OECD), "R&D in Non-OECD Economies," *OECD Science, Technology and Industry Scoreboard 2007, R&D and Investment in Knowledge*, 2007, http://caliban.sourceoecd.org/vl=1275123/cl=28/nw=1/rpsv/sti2007/a-4.htm (accessed February 13, 2008).
[21] International Institute for Management Development, *IMD World Competitiveness Yearbook 2006*, as cited in Israel, Ministry of Industry, Trade, and Labor, "Invest in Israel: Where Breakthroughs Happen," http://www.investinisrael.gov.il/NR/rdonlyres/F1EEBC85-283B-45EE-820F-C656A2865FC8/0/IIIflyer707.pdf (accessed February 3, 2008).
[22] European Community Research and Development Information Service (CORDIS), "Israel: R&D Activities in Israel," http://cordis.europa.eu/israel/.
[23] OECD, "R&D in Non-OECD Economies."

R&D Spending as a Percentage of GDP (Horizontal Axis), 2005, and (Vertical Column) R&D Spending in Billions of Current US$ in Terms of Purchasing Power Parity (PPP), 2005



Source: OECD, "R&D in Non-OECD Economies," *OECD Science, Technology and Industry Scoreboard 2007, R&D and Investment in Knowledge*, 2007, http://caliban.sourceoecd.org/vl=1275123/cl=28/nw=1/rpsv/sti2007/a-4.htm.

Figure 1. Gross Expenditure on R&D (GERD) in Non-OECD Economies, 2005

Israel's national R&D expenditures have seen significant growth in recent years, rising to present levels relatively quickly as a result of the continuing expansion of high-tech industries and the contraction of low-tech industries. During the period 1996 to 2004, Israel's national expenditure on civilian R&D rose 164 percent, from 2.8 to 4.6 percent.[24]

Another significant feature of Israel's R&D expenditure is its current distribution across the major performing sectors of R&D—academia, government, and business/industry. Much of the rapid growth in the share of resources directed to R&D in Israel comes from the business sector, which now performs nearly 75 percent of civilian R&D.[25] This high level of business-sector R&D involvement accompanies a significant relative decline in the role played by the government in R&D and S&T activities, including a decline in its role in providing the

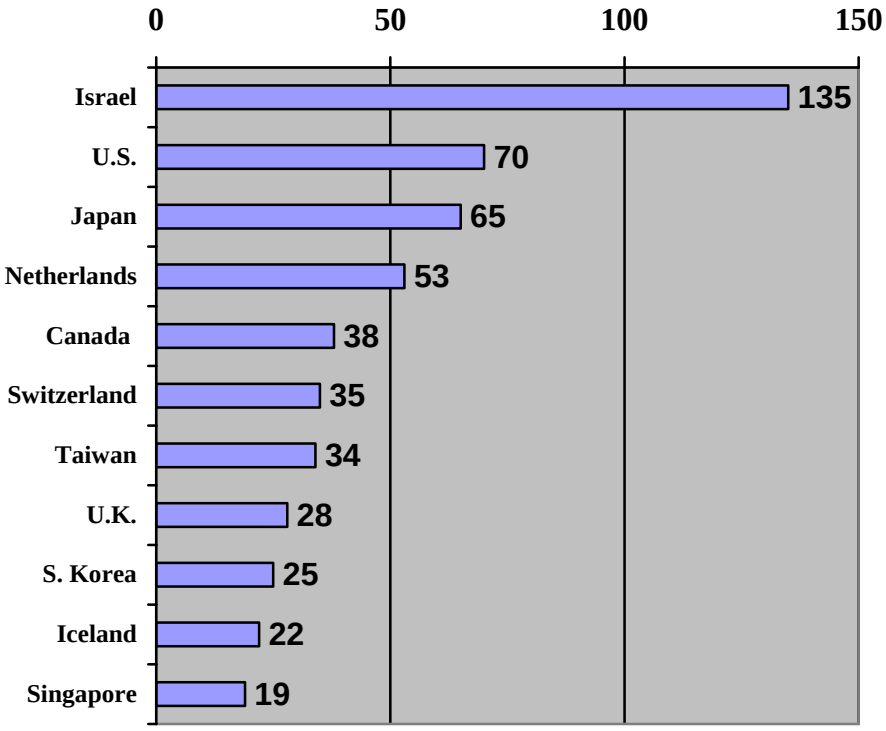
[24] Daphne Getz, Hani Mansour, Dan Peled, and Marian Shumaf-Tehawkho, "Science and Technology Indicators in Israel: An International Comparison" (Haifa: Samuel Neaman Institute, National Policy Research Paper Series, 2005), http://www.neaman.org.il/Neaman/publications/publication_item.asp?fid=585&parent_fid=488&iid=2826.
[25] Getz, et al., "Science and Technology Indicators."

infrastructure for their continued growth. With the growing predominance of business-sector involvement, Israel bears ever less resemblance to the less developed non-OECD and OECD countries, in which most R&D is performed by the government and higher education sectors. Israel's shift to a greater proportion of business R&D is viewed as significant, because, as stated by the OECD, "Industrial R&D is very closely linked to the creation of new products and production techniques and is therefore an important driver of economic growth."[26] Other analysts express concern about this shift in the relative weight of business R&D, insofar as they see the government's role as one of correcting market failures in R&D, for example, the failure of the private sector to invest sufficient resources in activities that lack a short-term payoff, such as education and research in new fields.[27]

Human Capital in Israeli R&D and S&T

In addition to Israel's exceptionally high levels of spending on R&D per unit of GDP, Israel has high levels of the second major economic growth–enabling resource, namely, human capital, especially human capital in the areas of S&T. Israel ranks among the world's leading countries with respect to the number of scientists and engineers, with particular strengths in such disciplines as math, physics, and computer science, as well as the life sciences and medicine.[28] Israel has the world's highest percentage of engineers, with 135 engineers per 10,000 employees, compared with 85 in the United States, 65 in Japan, and 28 in the United Kingdom (see figure 2).[29] With some 28,000 physicians for a country with a population of more than 7 million, the country also ranks first in the number of medical doctors per capita.[30]

[26] OECD, "R&D and Innovation: Creating and Diffusing Knowledge: R&D in Non–OECD Economies," *OECD Science, Technology And Industry Scoreboard 2005*, 2005, 20, http://fiordiliji.sourceoecd.org/pdf/a04.pdf.
[27] Haim Watzman, "Israeli Industry Asks for Boost to R&D." *Nature* 396, no. 6712 (1998): 611.
[28] De Fontenay and Carmel, "Israel's Silicon Wadi," 45.
[29] Global Source News Watch, "How Israeli High-Tech Happened," July 14, 2007, http://www.tmcnet.com/usubmit/2007/07/14/2784150.htm. See also Linda Sharaby, "Israel's Economic Growth: Success Without Security," *Middle East Review of International Affairs Journal* 6, no. 3 (September 2002), http://meria.idc.ac.il/journal/2002/issue3/jv6n3a3.html.
[30] Simon Griver, "The High-Tech Sector," *Facets of the Israeli Economy*," January 2001, http://www.mfa.gov.il/MFA/MFAArchive/2000_2009/2001/1/Facets%20of%20the%20Israeli%20Economy-%20The%20High-Tech%20Secto.



Source: Israel, Ministry of Finance, Economic Research and State Revenue Division, "Economic Outlook," http://www.mof.gov.il/research%5Fe/e09%5F00/aug00.pdf.

Figure 2. Engineers per 10,000 Employees, 2002

Relative to other countries, Israel has a heavier concentration of R&D-related employment in general and, in particular, a higher concentration in the business sector. In 2001 about 26.5 workers per 1,000 employees in the Israeli business sector were involved with R&D, compared to only 19.2 in Finland, 11 in Germany, and 6.9 in Ireland.[31] Of all employees in the business sector, the share of R&D workers in Israel is about 1.73 percent compared to 1.29 percent in Finland and 0.52 percent in Ireland.[32]

This relatively heavy concentration on R&D employment rests on a foundation of Israel's high level of general education in the population.[33] Approximately 24 percent of Israelis have university degrees, the world's third highest percentage after the United States and the

[31] Australia, State of Queensland, Smart State Council Working Group, *Smart Regions: Characteristics of Globally Successful Regions and Implications for Queensland*, August 9, 2006, http://www.smartstate.qld.gov.au/partnerships/SmartStateCouncilReportSmartregions.doc.
[32] Australia, State of Queensland.
[33] Israel News Agency, "State of Israel," http://www.israelnewsagency.com/israel484848.html (accessed January 29, 2008).

Netherlands, and 12 percent of the workforce possesses advanced degrees or doctorates. In terms of subject areas in the education system, the state has emphasized science and technology as national priorities and invested accordingly. In the realm of higher education, Israel has seven major universities, all world-class research institutions, among them the Israel Institute of Technology (called the Technion), which focuses on engineering, and the Weizmann Institute of Science, which is fully dedicated to research in the sciences, especially the life sciences. The remaining five—the Hebrew University, Tel Aviv University, Ben Gurion University of the Negev, Bar Ilan University, and the University of Haifa—are general universities with slight differences in academic content (see table 1). In addition, Israel has about 60 other accredited institutions of higher education, which generally are not defined as universities but as colleges.

Table 1. Israel's Universities

University	Location	Estab. Date	Remarks	Web site
Weizmann Institute of Science	Rehovot	1949	Fully dedicated to research in the sciences.	http://www.weizmann.ac.il
Technion—Israel Institute of Technology	Haifa	1924	Primarily deals with engineering.	http://www.technion.ac.il
Hebrew University	Jerusalem	1918	General curriculum, but lacks engineering.	http://www.huji.ac.il
Tel Aviv University	Tel Aviv	1956	Only university with Arts faculty.	http://www.tau.ac.il
Ben Gurion University of the Negev	Be'er Sheva	1969	Mandated to develop the Negev region.	http://www.bgu.ac.il
Bar Ilan University	Ramat Gan	1955	Seeks to blend tradition and modern technologies.	http://www.biu.ac.il
University of Haifa	Haifa	1963	Emphasizes humanities, social sciences, and equal opportunity.	http://www.haifa.ac.il
Source: Based on the Web sites of the universities.				

Israel's universities continue to expand their well-developed capacities to upgrade the workforce in technology. For example, the Technion recently planned to expand the number of undergraduate computer science majors from 1,200 to 1,500, rendering its computer science

department one of the largest in the world. Israel also benefits from the experience of the many technically minded Israelis who study and work for a time in Europe and the United States.[34]

Besides the investment and priority given education, a further source of Israel's wealth in human capital, especially in high-tech fields, has proven to be the military. The Israeli military is a national institution that has created the atmosphere for technological entrepreneurship. Military service in the Israel Defense Forces (IDF) is compulsory, and the Israeli military operates a scheme whereby talented trainees are selected for elite specialized units for computing and engineeering and given opportunities to develop their own technology-related projects.[35] On leaving the units, the trainees retain ownership of any intellectual property they produce in their projects.[36] These projects have been the source of many spin-off companies in civilian industry.[37] The military's technology trainees also benefit from the personal networks established during their service in the special units. Such networks have often formed the basis for later partnerships in industry.[38] The co-founders of many high-tech companies developed their relationships while working together in the military. Military service also provides trainee engineers and computer scientists with a practical problem-solving mentality prior to further university training. The human capital–generating effects of Israel's military service and their spillover benefits to the overall economy manifested themselves most clearly at the end of the Cold War, when the defense industries suffered a sharp slump in sales. The slump necessitated defense industry retrenchment, forcing many military-trained engineers and technicians in defense-related R&D to use their R&D skills in civilan high-tech industries.[39] This infusion of talent into the civilian economy gave it a large boost and contributed in a major way to Israel's high-tech takeoff in the early 1990s.

A final source of Israel's wealth in human capital in S&T is immigration. Both the amount and quality of human capital within Israel have been augmented by immigrant flows. Since its founding, Israel has received successive immigrant waves, some bringing above-average scientific training. The latest and largest influx of scientific expertise came with the

[34] De Fontenay and Carmel, "Israel's Silicon Wadi," 46. See also Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel," *Invest in Israel*, 6, http://www.moit.gov.il/NR/rdonlyres/4C221B00-EAAB-4054-9864-851C3FBFEDD6/0/LifeSciencesinIsrael2006.pdf.
[35] Breznitz, "Collaborative Public Space."
[36] Breznitz, "Collaborative Public Space."
[37] Breznitz, "Collaborative Public Space."
[38] Breznitz, "Collaborative Public Space."
[39] Breznitz, "Collaborative Public Space."

wave of immigration from the former Soviet Union that began in 1989. From 1990 to 2000, with a peak in 1991, more than 1 million people came to Israel, some 200,000 in the first two years and more than 70,000 on average per year over the next eight years.[40] These new immigrants, who increased Israel's population by 20 percent, have an even more impressive educational profile than the average Israeli. Given the Soviet Union's traditional strength in the theoretical sciences, the new arrivals added to Israel's already substantial strengths in mathematics.[41] In addition, Israel saw a doubling of its per capita ratio of scientists and engineers, already one of the highest in the world.[42] The immigrant scientists, who registered with the Israeli Ministry of Absorption, received some government help to utilize their expertise in the technical and engineering groups at ICT firms. The proficiency of many immigrants in R&D disciplines, such as advanced materials and new industrial processes, has proven complementary to the country's expertise in software, semiconductors, medical equipment, biotechnology, electronics, and communications.[43]

Israel's wealth in technological human capital stemming from the country's educational investments, the high-tech training of military personnel, and immigration ensures Israel a comparative advantage in high-tech activities that are intensive in the use of skilled labor, such as software development.

Indicators of Inventive Performance in Science and Technology

Israel's high ranking on measures of key inputs to the R&D system—national R&D expenditures and skilled human resources—is matched by an equally impressive showing on measures of key achievements, or outputs, of the system. Standard proxies for the output of R&D activities or inventive performance include such measures as patents and scientific publications and citations. Other indicators of R&D strengths include achievements related to the economic exploitation of R&D results, for example, the number of high-tech or innovation-based start-ups, the concentration of R&D centers or units within firms, the level of venture capital available to innovators, the number of high-tech public offerings on stock exchanges, and the level of high-

[40] Richard Stone, "Israel Hits Rich Seam of Ex-Soviet Immigrants," *Science* 284, no. 5416 (1999): 893.
[41] Stone, "Israel Hits Rich Seam of Ex-Soviet Immigrants," 894.
[42] Kahane and Raz, "Innovation Projects in Israeli Incubators."
[43] Griver.

tech exports produced by the economy. Such indicators measure R&D-based technological dynamism.

Patents

Israel's R&D activities, as measured by international patent-related data, are highly productive and increasingly innovative over time. Relative to population size, Israel ranks only behind the United States and Japan in the number of patent applications since 1999 to the U.S. Patent Office, and that number has doubled since 1995.[44] When the number of patent applications is measured relative to R&D expenditures, a similar picture of growing innovativeness emerges.[45] Among non-OECD economies, Israel has the highest patent-to-GDP ratio, as well as the highest patent-to-population ratio.[46] In fact, Israel is a rare case of a late developing country that has managed to close the gap with advanced economies in patenting-per-capita ratios.[47] Normalized for Israel's population size of about 7 million, Israel exceeds the OECD average in its number of patent families. In absolute terms, Israel accounts for less than 1 percent of all patent families, on a par with Australia and Belgium.[48]

Israel's patenting profile points toward innovative activities in a wide array of technologies. An analysis of the top classes of patents shows Israeli companies to be very active in communication and optics hardware, image and data analysis, the life sciences, and power and energy. A number of U.S. multinational semiconductor companies that have located large telecommunications R&D centers in Israel do extensive patenting in the area of semiconductors.[49]

Scientific Publications and Citations: Academic Research Output

Besides patenting activity, another measurable output that serves as an indicator of Israel's innovation-promoting R&D is the level of scientific publications. Relative to both GDP

[44] Trajtenberg, "Innovation in Israel, 1968–97."
[45] Trajtenberg, "R&D Policy in Israel."
[46] Israel, Ministry of Finance, International Affairs Department, OECD Coordinator, "Universal Credibility: Significant Player," 2007, http://www.oecd.gov.il/?id=16#_ftnref1.
[47] Israel OECD.
[48] Organisation for Economic Co-operation and Development (OECD), *OECD Science, Technology and Industry Outlook 2008* (Paris: OECD, 2008), 170, http://www.oecd.org/dataoecd/18/37/41559762.pdf.
[49] Trajtenberg, "R&D Policy in Israel."

and population, Israelis have long ranked high in the number of scientific papers they publish in international journals. As early as 1968, the year in which the state officially began its civilian R&D industrial policy program, Israel topped the international table in academic-publications-to-GDP ratio, a position Israel has retained.[50] In 2001, on a per capita basis, Israeli academics published more scientific articles (110 for every 10,000 persons) than any other academics in the world.[51] A high citation rate of Israeli scientific publications is an indication of their quality. Between 1996 and 2006, in absolute terms, Israel ranked sixteenth among the world's top countries for scientific paper citations, and, in relative terms, with a population of about 7 million, it ranked much higher.[52] According to *Nature* in 2004, Israel's national science citation intensity, measured as the ratio of scientific citations of all papers to the national GDP, is equivalent to the strongest performers by this measure, in order: Switzerland, Sweden, Finland, and Denmark.[53] In 1997 Israel ranked second behind Switzerland in academic papers per capita and third behind Switzerland and Sweden in citations per capita.[54] Israel's relative dominance in publications in the fields of mathematics and computer sciences is especially strong.[55]

The Creation and Financing of New High-Tech Companies

Besides patents and publications, further output or performance indicators of Israel's R&D strengths in S&T relate to accomplishments that R&D activities permit in the economy. Such accomplishments, as previously noted, include the creation of high-tech start-ups, the generation of a strong VC industry, the public offerings of companies on stock exchanges, the location by multinationals of their R&D centers in Israel, and a growing ratio of high-tech exports to other exports.

Israel is second only to the United States on a per capita basis in its ability to generate new, technology-based companies.[56] The country has produced, according to some counts, more

[50] De Fontenay and Carmel, "Israel's Silicon Wadi," 46.
[51] Griver.
[52] Ernst and Young, "Beyond Borders Global Biotechnology Report 2007," http://www.ey.com/Global/assets.nsf/International/Industry_Biotechnology_Beyond_Borders_2007_Full/$file/BeyondBorders2007.pdf.
[53] European Community Research and Development Information Service (CORDIS), "Israel: R&D Activities in Israel."
[54] De Fontenay and Carmel, "Israel's Silicon Wadi," 46.
[55] Griver.
[56] Israel Valley, "Israel: The New Silicon Valley," 2007, http://www.israelvalley.com/news/2007/10/11/13406/israel-special-israel-the-new-silicon-valley-context-and-economic-model-of-israel.

than 4,000 start-ups in the past few years. The lowest count put the number at 1,500.[57] These new businesses—almost all small- and medium-sized—tend to imitate the development path of a U.S. start-up company. Like U.S. high-tech start-ups, Israeli start-ups, e.g., PowerDsine, Schema, and Wintegra, are highly product-oriented, producing innovative, market-focused products. Such firms seek funding from, and have proven attractive to, the robust VC industry that has co-evolved in Israel with the proliferating start-ups.[58]

Israel now has one of the deepest per capita VC bases in the world, receiving VC financing from both within and outside Israel. Ranked second after the United States for VC availability by both the World Economic Forum and the International Institute for Management Development, Israel is the nation that has most successfully adopted the Silicon Valley–type practice of providing seed money to new companies.[59] Israel claimed more than US$1.62 billion of funds raised in 2006 from foreign and Israeli VCs—a 21 percent increase over the previous year.[60] According to the Israel Venture Capital (IVC) Research Center, established in 1997 to monitor Israel's VC industry, Israeli VCs raised US$2.52 billion in the 2004–6 period.[61] According to the founder of Gemini, a large Israeli VC fund, the country attracts twice as many VC investments as the whole of Europe.[62] The depth of the VC sector is widely regarded as both an indicator of, and a key to, Israel's success in exploiting the economic potential of its R&D.[63]

When Israeli start-ups graduate from their VC-backed early stages, they typically seek the greater financing that is needed for later-stage development through either public listings on the world's stock exchanges or through mergers. Apart from the United States and Canada, Israel has more companies publicly traded on the U.S. exchanges—mainly NASDAQ—than any other country.[64] These listed Israeli companies—more than 80 percent of which are high-tech

[57] Joel Bainerman, "What Happened to Israeli High-tech in the 1990s?," http://www.joelbainerman.com/pages/what_happened7.html (accessed February 11, 2008). The figure of 1,500 comes from the high-tech research firm D&A, which has Israel's most comprehensive database of start-ups. According to Bainerman, D&A's database is better even than that of the Office of the Chief Scientist in the Ministry of Industry, Trade, and Labor.
[58] Avnimelech and Teubal, "VC-Start-up Co-Evolution and the Emergence and Development of Israeli New High-tech Cluster."
[59] "Israel: Of Missiles and Microchips," *Economist*, September 1, 2006, http://globaltechforum.eiu.com/index.asp?layout=rich_story&doc_id=9298&title=Israel%3A+Of+missiles+and+microchips&channelid=4&categoryid=31.
[60] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech (Novel Efficient Water Technologies), "Water: The Israeli Experience," http://www.cambici.com.br/download/Israel-newtech-interim-brochure060907.pdf.
[61] Avnimelech and Teubal, "VC-Start-up Co-Evolution."
[62] Avnimelech and Teubal, "VC-Start-up Co-Evolution."
[63] Australia, State of Queensland.
[64] Avnimelech and Teubal, "VC-Start-up Co-Evolution."

companies—operate in a broad range of technological sectors. Additional Israeli companies have made public offerings on European exchanges, and many high-tech firms are traded on the Tel Aviv Stock Exchange.[65] In 2006 initial public offerings (IPOs) of Israeli technology companies raised nearly US$7 billion on various stock exchanges.[66] Israel boasts a list of globally successful Israeli technology firms, including, for example, Amdocs, Check Point, Comverse, and Saifun Semiconductors.[67]

Besides public listing on stock exchanges, another avenue for start-up maturation and company growth is through merger and acquisition buyouts. Some Israeli start-ups achieve sufficient success to absorb other companies.[68] Other companies—almost always start-ups—attract acquisition by multinational corporations (MNCs).[69] MNCs typically acquire start-ups in Israel because of their innovative products and, often, because of their R&D expertise. For example, U.S.-based Computer Associates acquired one of Israel's leading network/data security firms, Memco, and made the acquisition the global center of its data security products development.[70] In 2006, in the largest acquisition of an Israeli company to that date, Hewlett–Packard paid U$4.5 billion for Mercury Interactive, a management software and services company.[71] Acquiring a small Israeli start-up became, starting in the 1990s, a common way for multinationals to establish R&D centers in Israel. By the 1990s, U.S. MNCs such as Intel had been establishing R&D centers in Israel for several decades, at first by setting them up from scratch. Large multinational companies were the first to recognize and exploit Israel's comparative advantage in R&D, and many—Intel, Digital, IBM, and Microsoft—chose to site their main or main non-U.S. development centers there. In 2006 Google and IBM announced that

[65] Griver.
[66] Harrison, "Israel's High-Tech Sector Continues to Rack Up Deals."
[67] "Israel's Technology Industry: Punching Above its Weight," *Economist*, November 10, 2005, http://www.economist.com/business/displaystory.cfm?story_id=5149411.
[68] See Griver, "The High-Sector," which gives the example of Amdocs as an Israeli company that in 1999 expanded by acquiring an overseas company, Canada's Architel, for US$358 million.
[69] See Griver for examples of purchasers and deals for Israeli companies, including:
- U.S. company BMC, which paid US$675 million for Israel's New Dimension, a developer of enterprise control, automation, and management software systems. The price was a record for an Israeli company;
- SunGuard of the United States, which paid US$210 million for the Herzliya-based company Oshap, a developer of real-time software systems for vehicle and aerospace production lines;
- America On-Line, which paid US$407 million to Mirabilis, a start-up whose "twenty-something" owners devised a unique program (ICQ) for notifying Internet-users if their friends are on-line;
- Germany's Siemens has bought several start-ups as well as Ornet;
- UK's Picker has acquired part of Elscint's medical-imaging business.

[70] De Fontenay and Carmel, "Israel's Silicon Wadi," 74.

they were expanding their R&D operations in Israel.[72] The R&D location decisions of such multinational companies bespoke numerous general benefits of locating in Israel, including the high quality of human capital; government incentives, e.g., government grants, tax holidays, or matching funds; and low personnel turnover rates that justified intense on-the-job training.[73] The high concentration of the MNCs' R&D centers in Israel, whether buyouts or new units, is a telling indicator of Israel's strengths in commercial high-tech R&D.[74]

High-Tech Exports and High Technology's Contribution to Economic Growth

Another output indicator of Israel's R&D intensity and technological dynamism is the percentage contribution of the high-tech sector to exports and to economic growth. Israel has a high and growing level of exports of technology products, and its high-tech sector is a major contributor to its economy and economic growth. High technology made up about 55 percent of the nation's exports in 2003, compared with the OECD average of 26 percent.[75] If Israel's high-tech services, as well as goods, are counted, the figure is higher.[76] Israel's high-tech industries are strongly export-oriented and are involved in a network of trade and R&D agreements throughout the world that have given Israeli firms access to markets and to needed market knowledge and skills. The intimate interaction of Israeli venture capitalists and entrepreneurs with their counterparts in U.S. high technology has provided a particularly important conduit for sharing knowledge. High technology has an ever-growing importance in the Israeli economy, employing ever-larger percentages of the workforce. In 2000 the sector accounted for 25 percent of GDP and continues to contribute significant amounts of total annual gross national product (GNP) growth, with ICT alone accounting for 70 percent of growth.[77]

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[71] Harrison.
[72] Nicky Blackburn, "Five Years of Israeli Innovation and Excellence," *Israel21c* Web site, October 29, 2006, http://israel21c.com.
[73] In the cases of Intel and Microsoft, an additional, personal factor was operative for their R&D location decisions in Israel. The two companies each had a prominent Israeli researcher working in the United States who pressured the firm to open an Israeli site so he could return home. Intel took this step in 1974. See De Fontenay and Carmel, "Israel's Silicon Wadi," 70.
[74] De Fontenay and Carmel, "Israel's Silicon Wadi," 72.
[75] "Israel's Technology Policy: Punching Above Its Weight."
[76] Breznitz, "An Iron Cage or the Final Stage?"
[77] Israel, Ministry of Foreign Affairs, "Economy: Sectors of the Economy," October 1, 2006, http://www.mfa.gov.il/MFA/Facts+About+Israel/Economy/ECONOMY-+Sectors+of+the+Economy.htm.

INDUSTRIAL POLICY: R&D-SPEARHEADED HIGH-TECH GROWTH

Israel's impressive R&D resources and S&T achievements as measured by various input and output indicators owe a great deal to extensive involvement by the Israeli government. Government policy and actions were key to the emergence, early success, and continued flourishing of Israeli high technologies. Like governments in many other small countries and many advanced economies other than the United States, the Israeli government actively promotes economic development through an explicit industrial policy.[78] Israel's industrial policy took shape in the late 1960s, when the Israeli government extended its development support beyond the academic and military sectors to the business sector with the formulation of an S&T policy for civilian industry. According to Israel's policymakers at the time, Israel's industrial future lay in its ability to use "its extensive scientific research capabilities to create science-based industries."[79] As they saw it, Israel was deriving insufficient benefit for the economy from its high-quality R&D capabilities, which had the potential to be the source of a flow of sophisticated exportable products.

Israel had no dearth of prowess in research in the late 1960s, either basic or applied. From the early days of the state, Israel considered research and technology as crucial for national development and emphasized the role of government support. Until the late 1960s, however, the government had directed its resources and support for R&D primarily to the academic system and, to a lesser extent, to military-dominated industry. As a result, Israel's R&D prowess remained concentrated within its world-class universities and in the military sphere. With the end of the Six-Day War in 1967, defense R&D received a major boost, because France, hitherto Israel's largest supplier of sophisticated weaponry, imposed an arms embargo on Israel.[80] The embargo immediately prompted the Israeli state, anxious to gain greater self-sufficiency in weapons, to pour large amounts of money and R&D power into military technology efforts.[81] This overhaul of military R&D ultimately led, in the 1970s and 1980s, to a sophisticated local

[78] Trajtenberg, "R&D Policy in Israel," 3.
[79] Dan Breznitz, "Diffusion of Academic R&D Capabilities as an Industrial Innovation Policy?—The Development of Israel's IT Industry" (Massachusetts Institute of Technology, Industrial Performance Center (MIT IPC) Working Paper IPC–04–006, May 2004), http://web.mit.edu/ipc/publications/pdf/04-006.pdf.
[80] Dan Breznitz, "Innovation-Based Industrial Policy in Emerging Economies? The Case of Israel's IT Industry," *Business and Politics*. 8, no. 3 (2006), http://ssrn.com/abstract=953401. Israel's alliance with the United States began in earnest after the 1973 war, but the United States has never allowed Israel access to a number of crucial technologies.
[81] Breznitz, "Innovation-Based Industrial Policy in Emerging Economies?"

technological arms industry with competencies in avionics, communications, computing, and imaging, and to success in the global weapons export market. However, the late 1960s had not just confronted Israel with the French weapons embargo and the need for weapons self-sufficiency. The state also saw its first economic recession in the late 1960s, which brought home to policymakers weaknesses in the civilian sectors of the economy. These policymakers, like many in economic development circles, believed that the economic role of state intervention was to remedy market failures, and they saw evidence of market failure in the limited payoff for the civilian economy from Israel's sophisticated R&D capabilities.[82] The market failure consisted in the unwillingness or inability of private firms to incur the risks or burdens that R&D activities entail. The goal of Israeli S&T industrial policy first articulated in 1968 was thus to remedy this market failure by jump-starting and bolstering R&D in business enterprises, in order to promote the growth of the economy from R&D-based innovation and commercialization.

Israel's focus on indigenous science-based industrial development and the leveraging of R&D—both of which have continued, with some adjustments, to the present—was an unusual policy choice among late-developing, less-developed economies that sought to grow via technology, e.g., Ireland or Taiwan.[83] The more usual route laid out in the industrial policies of such economies has been to embark on technology-led growth by starting with low-level assembly of high-tech products (often for foreign companies), moving later to more sophisticated types of production and ultimately to R&D-based production. Israel bypassed this usual sequence, deciding instead that it would exploit its R&D advantage from the outset as the springboard for economic growth.

Research Policy: Particular Elements

The Israeli government reaffirmed its R&D policy decision repeatedly over the decades. One such example is the 1984 Law for the Encouragement of R&D, which consolidated Israel's support of business-sector R&D. In the words of the law, the government committed itself to promote knowledge-intensive industries by supporting "research aimed at new knowledge with

[82] Trajtenberg, "R&D Policy in Israel," 34.
[83] Dan Breznitz, "Innovation and the State—Development Strategies for High-Technology Industries in a World of Fragmented Production: Israel, Ireland, and Taiwan," *Enterprise & Society* 7, no. 4 (2006): 675–85 (via Proquest).

the purpose of creating commercially useful products, processes, or improvements thereof."[84] The policy approach expressed in the 1984 law was further affirmed in a large number of policy decisions and budgets, including a 2002 law that established the National Council for Civilian R&D (NCCRD), a body whose mandate is to build a long-term national S&T infrastructure.[85]

While articulating Israel's general industrial policy goal—to spur innovation-based industrial development by supporting R&D processes—Israel's general policy statements also defined specific elements of its policy. Key decisions about the exact approach to leveraging product R&D included the following:

- The decision to rely primarily on private firms and entrepreneurs—as opposed to public-sector organizations or institutes—to be the actual performers of industrial R&D
- The decision that the government, when offering support for R&D, would abstain from favoring research in particular or targeted S&T fields
- The decision to develop local leading companies based on innovation, rather than to promote development by inviting foreign companies to set up low-level manufacturing operations initially, on the assumption that higher-level activities would emerge later
- The decision to actively support linkages between Israeli companies and foreign companies and financial markets, especially firms and financial markets in the United States

In the decision to rely on the private sector to carry out industrial/commercial R&D, Israel differed from some other late-developing countries, such as Taiwan, which relied more heavily on government institutes as the performers of research for product development. In Israel, government research organizations are few and operate in very selected areas (e.g., the Volcani Center for research in agriculture and the National Center for Mariculture). Otherwise, Israel promotes the development of research capabilities primarily by private firms and entrepreneurs and supplies financial backing to R&D projects developed and executed by private actors. Israel's choice of the private avenue has had a substantial influence on the degree of market orientation of subsequent research and resulting products.[86]

[84] From the 1984 law, as cited in European Community Research and Development Information Service (CORDIS), *ERAWATCH Research Inventory Report: Israel*, 2006, http://cordis.europa.eu/erawatch/index.cfm?fuseaction=ri.content&topicID=373&countryCode=IL&parentID=4.
[85] *ERAWATCH*.
[86] Trajtenberg, "R&D Policy in Israel," 11.

In the state's second significant decision—that concerning control over research topics—Israeli policymakers opted for a minimum of control, choosing, for the most part, to avoid targeting specific sectors or technologies for support. In providing subsidies and other backing for R&D projects, policymakers stipulated only that the R&D activity of individual companies be oriented to new and/or improved products and processes, primarily for export. In contrast to targeted support programs, Israel's R&D support programs mostly have been open to any R&D projects accepted by scientific reviewers, regardless of the firm's industry, sector, product class, or technology.[87] Called horizontal programs, such non-targeted R&D support programs provide a 50 percent (or, recently, higher) subsidy to every R&D project that meets specific standards of quality.[88]

The third decision involved in Israel's industrial policy was to support fledgling indigenous companies in their R&D efforts, while not offering incentives to foreign technology companies to site low-level assembly work in Israel. Unlike other late-developing countries, such as Ireland, Israel's industrial policy entailed no effort, for instance, to improve infrastructure to attract foreign manufacturing operations. On the other hand, uniquely in the less developed world, Israel offered incentives to MNCs if they chose, as many high-tech giants have, to open R&D centers in Israel. MNCs were encouraged to buy Israeli high-tech start-ups, with their patents and talent, and to transform them into R&D centers.[89]

Israel's fourth industrial policy decision was to encourage links between local and foreign companies, investors, and financial markets. In fostering such local–global linkages, Israel did not limit its role to that of a promoter of Israeli companies in various foreign markets. Rather, Israel paid close attention to the assistance its local companies might need abroad, for example, to connect to and operate in foreign financial markets.[90] The state actively encouraged some local firms to publicly list on foreign stock exchanges, as well as on local ones.[91] The state also encouraged Israeli and foreign companies, especially U.S. firms, to form partnerships in which

[87] Trajtenberg, "R&D Policy in Israel," 35.
[88] Dan Breznitz, "Industrial R&D as a National Policy: Horizontal Technology Policies and Industry-State Co-Evolution in the Growth of the Israeli Software Industry," *Research Policy* 36, no. 9 (November 1, 2007): 1465 (via Proquest).
[89] Breznitz, "Industrial R&D as a National Policy."
[90] Dan Breznitz, *Innovation and the State*: *Political Choice and Strategies for Growth in Israel, Taiwan, and Ireland* (New Haven: Yale University Press, 2007), 11.
[91] Breznitz, "Industrial R&D as a National Policy."

the Israeli firms focused on R&D while the foreign firms focused on marketing and sales.[92] In addition, the state took various initiatives not only to develop an indigenous VC industry, but also to ensure intimate relationships between it and U.S. capital markets, as well as close contacts with European Union (EU) investors and grant-makers.[93]

Organizational Vehicles of R&D Policy

In the process of formulating its industrial policy and refining its policies to promote industrial/commercial R&D, Israel also created the main organizational vehicle through which the government would implement its policies, the Office of the Chief Scientist (OCS) at the Ministry of Industry, Trade, and Labor (MITL) (until 2005, the Ministry of Industry and Trade).[94] The state established the Office of the Chief Scientist at that ministry in 1969, a year after Israel officially started its civilian R&D industrial policy program. The OCS, a centralized and powerful government body, was identified as the state's S&T industrial development agency and charged with promoting R&D activities in all S&T-related industrial sectors.

Commanding a budget in recent years of about US$400 million annually, the OCS at the MITL is responsible for a variety of industrial R&D support programs geared towards the development of products and high-tech start-ups. Support takes the form, most notably, of providing individual grants and subsidies for business-sector R&D; promoting academia–industry cooperation in R&D consortia; organizing technology incubator programs; overseeing numerous binational funds and agreements; and fostering the emergence of venture capital.[95]

In addition to MITL, another major actor in the Israeli civilian R&D arena, especially in the area of science research policy, is the Ministry of Science and Technology (MOST), although its budgetary resources and programs are smaller than those of the MITL OCS.[96] The MOST, established in 1982, oversees basic scientific research in the academic research complex from

[92] De Fontenay and Carmel, "Israel's Silicon Wadi," 72.
[93] *ERAWATCH*.
[94] Barbara Prainsack and Ofer Firestine, "Biotechnology in Israel 'Science for Survival': Biotechnology Regulation in Israel, *Science and Public Policy* 33, no. 1 (February 2006): 33–46 (via EBSCO).
[95] Gil Avnimelech and Morris Teubal, "Evolutionary Innovation and Technology Policy: A Four-Phase High-tech Policy Model," paper presented at the DRUID Summer Conference 2006 on Knowledge, Innovation and Competitiveness: Dynamics of Firms, Networks, Regions and Institutions, Copenhagen, Denmark, June 18–20, 2006, http://www2.druid.dk/conferences/viewpaper.php?id=363&cf=8.
[96] Israel, Ministry of Science, Culture, and Sport, "Milestones in the Development of Israel's Ministry of Science and Technology," http://www.most.gov.il/English/Units/Science/About/Milestones+in+the+development+of+Israels+Ministry+of+Science+and+Technology.htm (accessed March 4, 2008).

which Israel's overall research strengths historically emanated. The MOST administers funding for research centers in the major research universities and has defined six priority areas for targeted research, setting up six national committees to coordinate it. The areas are advanced materials, biotechnology, ecology, electro-optics, information sciences, micro-electronics, and water.[97] The Ministry is also responsible for international academic research agreements for basic research. For example, along with the Israel Science Foundation, it oversees Israel's participation in developing the ATLAS detector for the Large Hadron Collider experiment at the European Center for Nuclear Research; the experiment's goal is finding the Higgs boson, the fundamental source of all mass.[98] Other governmental agencies provide support for R&D in areas of direct interest to them.[99]

In recent years, the government has sought to improve the coordination of civilian research activities across both the academic and business sectors. In 2002, with the passage of the National Council for Civilian R&D (NCCRD) Law, for example, the government specified a comprehensive R&D policy that encompasses all civilian R&D activities. As a means of implementing this policy, the government established the NCCRD, which advises the government on all subsystems of civilian R&D.[100] An additional initiative was the establishment of the Forum of the Chief Scientists through which the chief scientists of various ministries oversee all government-supported R&D, whether it is carried out by academic institutions, the industrial sector, or the government's small number of national institutes.[101]

Innovation Programs of the Office of the Chief Scientist of the Ministry of Industry, Trade, and Labor

As has been noted, the OCS at the MITL—the main branch in which the government has embedded its R&D and S&T policies—operates several programs to promote industrial/commercial R&D and entrepreneurship-led growth.

[97] *ERAWATCH*.
[98] Israel Science Foundation, "About ISF," http://www.isf.org.il/english/about.asp (accessed March 3, 2008).
[99] *ERAWATCH*.
[100] *ERAWATCH*.
[101] *ERAWATCH*.

Grants to R&D-Performing Firms: To Jump-Start Innovation and Entrepreneurship

Israel's grants program is the backbone of the government's support for business-sector R&D.[102] Initiated when Israel began its industrial policy in the late 1960s, the grants program was to serve, in effect, as a substitute for the private investment that would be needed to commercialize R&D-based innovations. The government provided funding to jump-start technological entrepreneurship because the supply of private capital was judged to be inadequate until the takeoff of Israel's ICT-based cluster growth in the 1990s,. Serious economic troubles in the early 1980s increased the need to realize economic payoffs from Israel's long-term investments in human capital and R&D assets in S&T and prompted the passage of the 1984 R&D Law, which consolidated Israel's support of business-sector R&D. After the law's passage, OCS grants to knowledge-intensive industry increased, and software development became eligible to receive R&D grants.[103] Moreover, the new law recognized the need to increase support to individual start-up companies, allowing them to receive grants that cover 66 percent of the total development costs for new products.[104] In the late 1980s to early 1990s, during the period of severe retrenchment of military industries, OCS grants were the key government tool used to encourage highly educated but underemployed scientists and engineers to think in an entrepreneurial fashion about ways to sell their skills in the civilian market. During this period, grants made up nearly all the OCS disbursements to civilian industry.

Although OCS R&D grants now constitute a somewhat lower percentage of government assistance to the business sector, they are still important and still function in the same way as before. Currently, the OCS of MITL disburses to companies some US$400 million a year in grants covering between 30 and 66 percent of R&D costs for new and/or improved products and processes for export. From subsequent sales of successful products, the OCS recoups about US$100 million per year in royalty payments. The program is open to all firms, whether veteran or start-up, and does not discriminate as to sector, specific industry, technology, or type of R&D projects.[105]

[102] Trajtenberg, "R&D Policy in Israel."
[103] Breznitz, "Industrial R&D as a National Policy."
[104] Info-Prod Research (Middle East) Ltd., "Israel: Investment Incentives," 1999, http://www.infoprod.co.il/country/israel2f.htm.
[105] Mani, *Government, Innovation and Technology Policy*, 13.

Technology Incubators: To Increase Firm-Building Capabilities and Managerial Skills

Technology incubators are another form of government assistance designed to foster innovation and entrepreneurship. The OCS initiated its Technology Incubator Program in the early 1990s, when Israel was a nascent high-tech cluster, in order to enhance the managerial and firm-building skill base among start-up and new immigrant entrepreneurs.[106] The program was prompted, in part, by the immediate need to help absorb the wave of scientists and engineers who were immigrating to Israel from the former Soviet Union. Israeli policymakers also noticed that start-ups in general had insufficient rates of success, largely, as they saw it, because of weak management. Designed to augment the already solid technical skills of would-be entrepreneurs with managerial know-how, the incubator program recruits scientists and entrepreneurs with the goal of helping them build a company that, within two to three years, could find sufficient funding to keep going.[107] Companies accepted into one of Israel's several dozen incubators qualify not only for mentorship, but also for a grant of 85 percent of each firm's approved budget, up to US$170,000 annually for two years.[108] Typically, some 50 percent of the accepted companies survive and attract investment or strategic partners.[109]

Venture-Capital Industry: A Service Industry for Israel's High-Tech Cluster

A third form of government assistance to the companies of Israel's nascent high-tech cluster consists of programs designed to kick-start certain sophisticated support and service industries for the cluster, including, most importantly, a VC industry. Grants for early-stage product development notwithstanding, Israeli technology firms suffered from a dearth of capital into the early 1990s. Recognizing that this dearth would jeopardize new company survival and growth, the OCS in 1993 established a government-run VC fund, Yozma, hoping that it would trigger the development of an Israeli VC sector. The pump-priming experiment succeeded, and the VC market grew rapidly throughout the 1990s to become one of the world's most developed.[110] Israeli VC funds quickly became the predominant source of financing for Israeli

[106] Gil Avnimelech, Dafna Schwartz, and Raphael Bar-El, "Entrepreneurial High-tech Cluster Development: Israel's Experience with Venture Capital and Technological Incubators," *European Planning Studies* 15, no. 9 (2007): 1181–98, http://www.informaworld.com/10.1080/09654310701529078.
[107] Avnimelech, Schwartz, and Bar-El.
[108] Griver.
[109] Avnimelech, Schwartz, and Bar-El.
[110] Avnimelech, Schwartz, and Bar-El.

start-ups—including many incubator graduates—and a key element in start-up proliferation and success. Although the availability of venture capital dipped during the global high-tech crisis of 2001, it remains a dominant form of new company financing; one that encourages risk-taking and thus boosts the proclivity of VC-backed firms to continue pursuing R&D and innovation.[111] Most capital for Israeli VC funds comes from foreign investors, including financial investors and high-tech MNCs that seek access to the R&D resources, talent, and patents of Israeli start-ups. The major source of capital is the United States, with lesser amounts coming from Asia and Europe, and still smaller amounts from Israel itself.[112] Most of the larger Israeli funds maintain offices in the United States and have ties with U.S. VCs and high-tech giants.[113] In addition, among the VC companies that invest in Israel, a significant percentage—often one-quarter—is foreign.[114]

Toward Cluster Renewal: Strengthening Global Links and University–Industry Collaboration

Following the launch and growth of the VC industry and the growth in the start-up–intensive high-tech cluster, Israeli policymakers in the OCS gradually shifted their attention from fostering support and services for the cluster to questions of its sustainability and renewal. Recognizing the importance of innovation and technological diversification within the cluster, they sought to redirect some assets toward sectors of the economy other than the dominant ICT sector.[115] This appreciation of diversification, deepened by Israel's high-tech-bust-generated recession in 2002, brought about something of a shift in national R&D and S&T policy priorities. The goal of OCS became to compensate for the market failure caused by private-sector investors that invested too narrowly in technologies offering short-run profit prospects. This market failure was one potential negative consequence of the government's positive achievement in fostering the growth of private-sector forms of finance, such as venture capital. As private expenditure for R&D-based innovation grew in percentage terms and came to predominate, and the role of the government as a co-funding agency decreased, considerations of short-term market success also

[111] Avnimelech and Teubal, 2006.
[112] Ian Limbach, "Israel's Cutting Edge with VCs," *Financial Times* (London), April 25, 2007.
[113] Breznitz, "Diffusion of Academic R&D Capabilities as an Industrial Innovation Policy?"
[114] *ERAWATCH*.
[115] *ERAWATCH*.

grew.[116] The policymakers at OCS aimed to counter this short-term profit focus in order to foster renewal forces within the cluster. Implementing this policy entailed diversifying the government's set of incentives with two types of programs: programs to strengthen university–industry collaborations, particularly in new technological areas, and programs to foster and broaden international cooperation and R&D funding.

The Israeli government has always played a role—a uniquely strong role compared to other countries—in supporting heavy academic involvement in industrial R&D and the transfer of knowledge and new ideas from academia to industry. Thanks in part to the commitment of the OCS to commercializing academic research, all of the major universities and the leading research hospitals in Israel now have special organizations to transfer technology to industry. Called technology-transfer companies (TTOs), these industrial liaison organizations stimulate work in new areas and technologies, and provide a forum for connecting Israeli scientific researchers and early-stage projects with investors, sponsors, and partners from companies seeking to benefit from Israeli innovation.[117] Israeli universities were among the first in the world to develop such TTOs, with Hebrew University's TTO, Yissum, leading the way as early as 1964. Yissum, like subsequent TTOs, is responsible for the management and licensing of a portfolio of the numerous patents developed within the academic institution. The best-known example of R&D-based innovation generated through such a university–industry TTO is the development by Yeda, the Weizmann Institute's TTO, of Copaxone—the first major innovative drug to be developed in Israel and to receive FDA approval.[118]

The Israeli state continues to exhibit its long-standing concern with improving academia–industry cooperation as a way to fuel innovation. It is this concern that has prompted the launch of most of the new OCS support programs that have appeared since 2000. A stream of new programs, including Magneton, Nufar, Zemer, Nataf, all address such cooperation. Others specifically aim to promote collaborative efforts in particular fields with perceived strong current growth potential, namely, biotechnology and nanotechnology (see table 2).[119]

[116] According to *ERAWATCH*, in 1995 the government funded more than 20 percent of the R&D expenditure by the industrial R&D system in Israel. The share of the government decreased to 11 percent in 2000 and to 8 percent in 2005.
[117] "Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel," 9.
[118] "Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel," 7.
[119] *ERAWATCH*.

Table 2. Recent Programs to Promote Renewal Forces Within Israel's High-Tech Cluster

Year	Program	Purpose
2000	Tnofa	Supports entrepreneurs in the pre-seed stage
2000	Magneton	Small industry–academia cooperation grants
2002	Generic R&D agreements with large firms	Supports multiple S&T fields
2003	Heznek fund	Enhances seed finance by private VC funds
2003	Large High-tech Companies Generic R&D support scheme	Supports multiple S&T fields
2004	Nofar	Supports academia–industry link in the fields of biotechnology and nanotechnology
2004	Specialized incubators for biotechnology start-ups	Supports early-stage biotech projects
2004	Tamir	Supports knowledge transfer from MNCs
2005	Nataf	Supports nanotechnology R&D

Source: Based on Gil Avnimelech and Morris Teubal, "Evolutionary Innovation and Technology Policy: A Four-Phase High-Tech Policy Model" (paper presented at the DRUID Summer Conference 2006 on Knowledge, Innovation and Competitiveness: Dynamics of Firms, Networks, Regions and Institutions, Copenhagen, Denmark, June 18–20, 2006), 11, http://www2.druid.dk/conferences/viewpaper.php?id=363&cf=8.

Whatever the exact stated aim of the cooperation-promoting programs initiated within the past half decade or so, they are all meant to serve the general aim of creating renewal forces within Israel's high-tech cluster by enabling the smooth development of new technological sectors and new market institutions.

The Israeli government also expects stimulus for innovation and cluster renewal to arise from stepped-up and broadened international cooperation in basic and applied R&D. The OCS has long promoted joint ventures in industrial R&D through partnership programs in binational and multinational R&D foundations, beginning with BIRD—the Israel–U.S. Bi-National Industrial Research and Development Foundation—set up in 1977. Besides funding project costs on a payback basis for successful projects, BIRD assists Israeli or U.S. companies in identifying partners for joint R&D projects. Projects thus far include, for example, peptide-based biosensors for human diagnostics, advanced chip sets for wireless devices, and computerized milking parlors.[120] In addition to BIRD, Israel has set up similar binational R&D foundations and funds with Canada (1994), Singapore (1996), and the United Kingdom (1999). Israel also has R&D agreements with Austria, Belgium, France, India, Ireland, the Netherlands, Portugal, and Spain, and it participates in the Framework Program of the EU's Commission on Science, Research,

[120] Griver.

and Development.[121] Such binational agreements, as well as Israel's broad range of free-trade agreements—with Canada, the EU, individual European countries, and the United States—give Israeli companies and researchers privileged access to the technological cutting edge, allowing them to stay abreast of fields with future potential.

AREAS OF R&D AND S&T STRENGTH AND PRIORITY

Among the world's young high-tech clusters, Israel is relatively well diversified, featuring a broad industrial composition. The core of the Israeli cluster lies in information and communication technology (ICT), especially cellular, data communications, electro-optics, enterprise software, hardware design, and Internet technologies.[122] However, the Israeli cluster has expanded beyond the compass of its strong expertise in ICT. In addition to ICT, Israel's primary growth areas now include the life sciences and, in particular, biotechnology and agrobiotechnology.[123] Two other current Israeli growth areas include energy (e.g., electricity storage and sustainable energy development) and environment (e.g., desalination, irrigation, wastewater, and water technology). The composition of start-ups in Israel has clearly been shifting somewhat. At the same time, Israel continues to hold its own in high-tech industries such as materials technology, medical equipment, and military technology. An analysis of the top classes of patents also shows Israeli companies to be very active in R&D-based innovation in communications and optics hardware, image and data analysis, the life sciences, and power and energy.

Information and Communication Technology

Israel has been a key player in global ICT industries since the early 1990s and has publicly listed companies in all the major subsectors. During the 1990s, the Israeli ICT industry as a whole achieved unprecedented growth, directly employing 70,300 people and reaching US$16.3 billion in sales by 2000.[124] In 2005, at US$14 billion, ICT products contributed 16

[121] Griver.
[122] Israel–Europe R&D Directorate for the EU Framework Program (ISERD), "Israel's R&D Capacity: A Promising Land," http://www.iserd.org.il (accessed January 10, 2008).
[123] De Fontenay and Carmel, 75.
[124] Breznitz, "An Iron Cage or the Final Stage?"

percent of business-sector GDP.[125] In 2002 ICT represented 45 percent of Israel's industrial exports. Israeli companies pioneered first in many hardware market niches, such as digital printing, printed circuit board inspection, and semiconductors. Later, especially from the mid-1990s on, they were active in software market niches, such as antivirus protection, encryption, firewalls, and voice-over-Internet protocols (VOIP). Israel's ICT industry remains divided between the older and more developed hardware sector and the younger software sector.[126] The range of Israeli activities in ICT is shown in table 3. All the founders or top officers of the companies listed in the table were previously active in defense-related high technologies, as is true for many leaders in Israeli ICT.

In terms of business strategy, the Israeli ICT industry has from the beginning been strongly product-based and export-oriented. The tendency to proceed expeditiously from R&D results to commercialization is reflected in the fact that Israel has the highest number of publicly traded companies on the technology-oriented U.S. NASDAQ, apart from the United States and Canada. Israeli ICT products are destined for the world's largest markets, competing on a par with products from top European and U.S. ICT firms. Despite its distance from markets, Israel is competitive in both hardware and software sectors of the industry, because of emphasis on products for sophisticated business customers, rather than products for the mass consumer market.[127] Israel's success in ICT also is attributable to the large VC industry that has co-evolved with ICT with government encouragement, and to Israel's intimate relationship with U.S. financial markets.[128] Israel's high-tech industry structure, which features numerous and diverse small high-tech firms, each following a Silicon Valley–style start-up model, also contributes to making the Israeli ICT industry, as one analyst put it, "the one most similar to Silicon Valley outside the USA."[129]

[125] Israel, Ministry of Foreign Affairs, "Economy."
[126] Breznitz, "An Iron Cage or the Final Stage?"
[127] De Fontenay and Carmel, 71.
[128] Avnimelech and Teubal, "VC-Start-up Co-Evolution."
[129] Breznitz, "An Iron Cage or the Final Stage?"

Table 3. Representative High-Tech Firms in Israel

Firm	Area of Expertise
BVR	Simulators, virtual studios
Check Point	Firewalls for Internet data security
Cubital	Fast prototyping machines
DSP	Speech processing devices
Elbit	Defense and medical instrumentation and communication systems
ESC	Laser surgery equipment
Gilat Communications	Very small aperture satellite terminals (VSAT)
Lannet	Data communication equipment
Magic Computers	General database software
Medis EL	Cancer diagnosis equipment
Nexsus	Two-way paging systems
NICE Systems	Computer telephony integration
Optrotech	Printed board inspection systems
Orckit	High-speed modems
RAD Computers	Data communication equipment
Tadiran	Communication and telephone equipment
Tecnomatix	CAD/CAM software for the automobile industry
Teldor Computers	Software development
Telrad	Telephone switching systems

Source: Based on Catherine de Fontenay and Erran Carmel, "Israel's Silicon Wadi: The Forces Behind Cluster Formation," in *Building High-tech Clusters: Silicon Valley and Beyond*, ed. Timothy F. Bresnahan and Alfonso Gambardella, 40–77 (Cambridge: Cambridge University Press, 2004).

Hardware: Cellular, Electronics, Internet, and Semiconductor Technologies

The hardware and electronics sector in Israel preceded the software sector by more than a decade and remains by far the larger, although not the faster-growing, sector.[130] With 55,800 employees and US$12.5 billion in sales in 2000, the hardware sector is about four times larger than the software sector, which has 14,5000 employees and revenues in excess of US$3.7 billion. This difference in scale appears even more marked in the data on R&D financing in Israel. Of Israel's total R&D expenditures in 1998, about 85 percent were focused solely on the hardware optical and communication electronics subsector.[131]

Israel's heavy (albeit in relative terms declining) investment in hardware development has continued to pay off in innovation, for example, with cutting-edge work in semiconductors

[130] Breznitz, "An Iron Cage or the Final Stage?"

and computer data storage products. One field of particular Israeli strength is electro-optics, including such areas as fiber optics, optical inspection systems, and electro-optics–based robotic manufacturing.[132] All Israeli universities have established electro-optics programs, as have the major high-tech MNCs operating in Israel. Israeli companies in the electro-optics subsector already numbered about 150 in 1999 and generated some US$2.5 billion in annual sales.[133] Successful firms included an optical networking systems firm, Chromatis, which U.S.-based Lucent acquired for US$4.7 billion in 2000, the largest foreign acquisition of an Israeli firm to that date. A significant electro-optics industry also operates in the military technology sector, including the firms Elbit, El-Op (now an Elbit subsidiary), Raphael (Israel's Armaments Development Authority), and Israel Aerospace Industries (IAI).[134]

Innovation in Israel's hardware sector, more than in software, remains divided between the country's numerous small high-tech start-ups and the R&D centers that large firms—mainly major U.S.-based multinational hardware and semiconductor firms—maintain in Israel. The Israel-based development centers of the multinationals have been making technological breakthroughs for some 30 years and continue to do extensive patenting in Israel.[135] Such R&D centers arise and grow mainly by two avenues—by internal company expansion or, with increasing frequency, by the acquisition and conversion of innovative Israeli start-ups into R&D units. By whatever means they arise, the large firms' R&D centers can claim notable achievements in global ICT, for example, the 8088 processor, which was selected to be the "brain" of the first PC, multimedia MMX technology, third-generation (3G) mobile network products, and Intel Israel's PXA800F processor, code-named "Manitoba."[136]

More recent innovations are of similar importance in worldwide computing; many are from Intel Israel, the largest private employer in the country.[137] Intel, which was in the first generation of multinational high-tech companies to invest in Israel, established its first design

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[131] Arnon Bentur, "Investment in Civilian R&D in Israel: Data as a Basis for Discussion in the Purpose of Developing a National Policy," *STE Working Papers Series*, Technion: Samuel Neaman Institute, 2002.
[132] ISERD, "Israel's R&D Capacity."
[133] Moshe Oron, "Électrooptics in Israel," Department of Electrical and Computer Engineering, Ben Gurion University, November 29, 2005, 4, http://www.ee.bgu.ac.il/~ilitop/Presentations/Keynote_Addr/Electrooptics RoadMap%202005-Oron.pdf.
[134] De Fontenay and Carmel, 50.
[135] Breznitz, "Diffusion of Academic R&D Capabilities as an Industrial Innovation Policy?"
[136] Intel Corporation, "Intel on the Map," http://www.intel.com/il/intel/english/index.htm (accessed December 29, 2007). In 2005 Intel Israel, which is among Israel's leading export companies, registered an export volume of US$1.2 billion—14 percent of the sum total of the exports from the country's electronics and information industry.

center there in 1974 and manufacturing centers in the 1980s.[138] Intel Israel now serves as an international development center for Intel worldwide, with four main development units—located in Jerusalem, Haifa, Kiryat Gat, and Petah Tikva—employing 5,200 people.[139] Intel Israel's R&D facility at Petah Tikva has been responsible for the company's developments and improvements in its Centrino mobile technology for laptops. The Centrino computer chips, developed by several hundred engineers over three years and unveiled in 2003, featured performance close to the latest Pentium 4, combined with low electricity consumption.[140]

Other advanced microelectronic products are in the pipeline from Israeli researchers in silicon photonics at Intel. Since the mid-1990s, researchers have worked on transistors that switch inside microprocessors optically, converting electronic signals to optic signals within the chip. In 2003 researchers at Intel Israel's Jerusalem facility succeeded for the first time in making optical chips based on silicon. This silicon-based chip, when substituted for standard electronic chips, will eventually—within the next five to 10 years—enable computers and telecom devices to operate at the speed of light, 10 times the current speed.[141] Such silicon-based chips, unlike previous optical chips made of other materials, have the potential to be mass-produced at the same cost as standard electronic chips. According to Intel Israel's researchers, the chip is

> a significant step toward building optical devices that move data around inside a computer at the speed of light. It is the kind of breakthrough that ripples across an industry over time, enabling other new devices and applications. It could help make the Internet run faster, build much faster high-performance computers and enable high bandwidth applications like ultra-high-definition displays or vision recognition systems.[142]

An additional advantage of the chips is that they can be manufactured at the same facilities in Israel where standard chips are now made, and they can eventually be integrated into optical systems that are immune to electromagnetic interference and cross talk.[143]

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[137] Intel Corporation.
[138] Intel's R&D location decision was seconded in the 1970s by National Semiconductor, which also established a design center in Israel.
[139] Intel Corporation.
[140] Israel21c, "Intel Launches Israel-Developed Centrino Chip Series," March 9, 2003, http://www.israel21c.net/.
[141] Israel21c, "Intel Israel's Breakthrough Revolutionizes Chip Development," April 25, 2004, http://www.israel21c.org/bin/en.jsp?enDisplay=view&enDispWhat=object&enZone=Technology&enDispWho=Articles%5El674&enPage=BlankPage.
[142] Israel21c, "Intel Israel's Breakthrough Revolutionizes Chip Development."
[143] Israel21c, "Intel Israel's Breakthrough Revolutionizes Chip Development."

As noted, Intel Israel, as well as other multinationals and a number of large Israeli firms, keep up their pace of innovation in part by acquiring Israel's start-ups. For example, in 2000 Intel Israel expanded its R&D activities into additional product platforms by acquiring Dialogic and DSPC, two Israeli companies with major research centers.[144] With the acquisition of Israel's Envara company in 2004, Intel gained leadership in the Wi-Max revolution for future generations of mobile computers and telephones.[145] With the acquisition of Israel's Oplus company in 2005, Intel expanded its development activities into the market of entertainment equipment.

The plethora of Israeli start-ups that are not acquired, although predominantly involved in software programming, are also sources of innovations in ICT hardware.[146] The small company Lenslet, for example, was established in 1999 with the aim of commercializing optical processing, which had for 30 years been limited to academic laboratories. Lenslet's R&D team developed and patented the world's first commercially available optical digital signal processor. Introduced in 2003, the new electro-optic processor, EnLight, operates 1,000 times faster than any known digital signal processor. This quantum leap in processing speed makes the processor suitable for applications requiring phenomenal speed, such as the automatic screening of massive amounts of data. Such screening is potentially useful for airport scanning; the analysis of intelligence data; battlefield applications; multimedia, cellular, and video compression; voice, face, and behavioral analysis; and weather forecasting.[147]

In addition to innovations that enhance computer-processing performance, Israeli companies are known for computer storage products, notably the flash technology that has made it possible to miniaturize and store large amounts of computer data on a portable silicon chip. An Israeli company, Kfar Sava-based M–Systems, founded in the mid-1990s by a former Israeli navy commander, was the first to patent and commercialize flash-based data storage as an alternative to hard and floppy disks.[148] M–systems, which originally created such storage for the

[144] Breznitz, "Innovation-Based Industrial Policy in Emerging Economies?"
[145] See Eric Griffith, "Intel Buys Israeli Chip Designer," *Wi-Fi Planet*, March 25, 2004, http://www.wi-fiplanet.com/news/article.php/3331411, and "Intel Israel on the Map," Web site of Intel Israel.
[146] Israel21c, "New Israeli Electro-Optic Processor is as Fast as a Super-Computer," October 19, 2003, http://www.israel21c.org/bin/en.jsp?enDisplay=view&enDispWhat=object&enZone=Technology&enDispWho=Articles^l528&enPage=BlankPage.
[147] Israel21c, "New Israeli Electro-Optic Processor is as Fast as a Super-Computer."
[148] Sharon Kanon, "Masters of Miniaturization," August 31, 2003, http://www.israel21c.org/bin/en.jsp?enDispWho=Articles%5El494&enPage=BlankPage&enDisplay=view&enDisp.

military, now markets several forms of portable key-chain-sized storage. One of these received the designation of "best product of the year" in 2001 from *PC Magazine* and other review sources. In July 2003, M–Systems introduced the world's smallest 1-gigabit flash-based storage product for mobile devices. The company's DiskOnKey line of products and the related DiskOnChip for mobile devices are small, high-capacity, tamper-proof, and consume little power. The Fast Flash Disk product line, M–Systems' most rugged, is designed to withstand temperature extremes, shocks, and changes in altitude. Besides applications in the military, the line has uses in aerospace, public safety, reconnaissance, and telecommunications and appears, for example, in black boxes, radar, and industrial automation. M–Systems, whose R&D is all done in Israel, has established cooperative relationships with major companies such as Motorola, Palm, and Toshiba and claims IBM and Microsoft among its largest customers, with overall sales already reaching US$70 million in 2003.[149]

Besides computer storage and computer speed, Israeli contributions to the development of commercial hardware have included Internet technologies and applications, e.g., wireless Internet and video chats and technologies for cellular telephony.[150]

Software: Internet Security, Network Performance, Streaming, Virtual Private Networks, and Voice Compression

Although Israel's ICT industry began and remains strong in computer and telecommunications hardware, much of Israel's ICT output is software. Israel has become a major international center for software design and development. Israeli software companies develop and manufacture a wide variety of software solutions, particularly in communications, security, and Internet technology. As with hardware, Israeli software is partly the province of Israel-based R&D centers of the world's largest computer companies. For example, Microsoft set up its first R&D centers outside of the United States in Israel in 1991 and recently developed most of the Windows NT and XP operating systems there.[151] However, software, less capital-intensive than hardware, is the realm par excellence of Israel's many shifting start-ups.

[149] Kanon.
[150] De Fontenay and Carmel, 50.
[151] United States, Department of Commerce, Stat–USA/Internet, "Background Notes: Israel," October 2007, http://www.stat-usa.gov/mrd.nsf/vwNoteIDLookup/NT002142D6/$File/X_7786627.PDF?OpenElement.

The Israeli software industry, fueled by R&D, developed out of the older and more successful hardware sector.[152] The software and telecommunications components of Israel's high-tech industry are now its primary drivers, although software, as measured by total sales, brings in less than hardware. Of the more than US$16 billion in ICT sales in 2000, software sales contributed somewhat less than US$4 billion.[153] However, software has enjoyed faster growth—23 percent annually in the 1990s—and by 1997, measured by sales per employee, surpassed the hardware sector. The Israeli software industry has always been primarily market-oriented. Initially—and unusually in small developing economies—the industry was nurtured mainly by local demand. After 1997, the market for Israel's software products beyond Israel's borders exceeded the local market.[154]

In software, as in hardware, Israel's main strengths lay and still lie in sophisticated applications and tools for institutions and business users, rather than products for the mass market. Israel pioneered in multiple software areas, including, notably, Internet security (firewalls and virus protection), network performance products, voice compression, streaming techniques, virtual private networks, and Internet telephony software (an innovation that originated in Israel).[155] Israeli developers also have a strong track record in mathematically based tools for encryption, content discovery and text analytics, image and data analysis, real-time collaboration, metadata management, application security, and service-oriented architecture.[156]

A recent example of Israeli achievements in software is a system adopted by the U.S. Federal Bureau of Investigation for computerized document and text analysis.[157] The system, a tool created by the Israeli R&D facility of Israel's ClearForest company, will enable bureau analysts to cope with the huge masses of security-related information that various intelligence

[152] For three accounts that discuss the software industry and the causes of its success, see Gad Ariav and Seymour E. Goodman, "Israel: Of Swords and Software Plowshares," *Communications of the ACM* 37 (1994): 17–21 (via Proquest); Breznitz, "An Iron Cage or the Final Stage?"; and De Fontenay and Carmel, "Israel's Silicon Wadi."
[153] Israel Association of Electronic and Information Industries (IAEI), "Israel Electronics Industries Profile," Tel Aviv, 2002, http://www.iaei.org.il/index-site.html. See also Israeli Association of Software Houses (IASH), "Software Industry Statistical Information," Tel Aviv, 2002, http://www.iash.org.il/content/SoftwareInds/Statistical Information.asp.
[154] Breznitz, "Innovation-Based Industrial Policy in Emerging Economies?"
[155] De Fontenay and Carmel, 50.
[156] IBM, "IBM Israel Software Lab (ILSL)," http://www.haifa.ibm.com/software.html (accessed January 5, 2008).
[157] Israel21c, "Israeli Technology Powers FBI's Counter-terrorism Data System," April 27, 2003, http://www.israel 21c.org/bin/en.jsp?enDisplay=view&enDispWhat=object&enZone=Technology&enDispWho=Articles^l383&enPa ge=BlankPage.

agencies collect. ClearForest is a leader in organizing and detecting patterns in unstructured information. The company's tools, ClearTags and ClearResearch, operating somewhat like an Internet browser, can instantaneously pull information from databases of scanned documents and other data. Then, as a powerful, customizable recognition tool, the system can quickly identify significant relationships among people and places. Other extremely high-power analytic software systems created in Israel include a voice stress analyzer. Created by the R&D center of the security-related Israeli company Nemesysco, Ltd., the patented state-of-the-art voice analysis technology detects the uniqueness and the emotional content of live or recorded speech and can be used to identify the speaker or the speaker's state of mind.[158]

Software R&D in Israel, although temporarily slowed by the high-tech crisis of 2000 to 2002, remains Israel's chief growth engine.

Biotechnology: Pharmaceuticals, Biomedical Devices, and Tools for Biological Information

Although ICT, particularly software, is Israel's strongest field, Israel has shifted its R&D emphasis somewhat since the high-tech crisis, moving more resources into R&D in life sciences–based industry, including biotechnology. In 2000 the government declared biotechnology a national priority and launched a program—Israel Bio-Plan 2000–2010—in order to place biotechnology high on the national agenda.[159] The government stepped up support for research with commercial potential, allocating a budget of US$100 million for new initiatives and establishing two technological incubators specifically dedicated to biotech start-ups.[160] Thanks in part to such increased support, the Israeli biotechnology sector has grown substantially. At the end of 2006, according to a 2007 report by Ernst and Young, "Beyond Borders: Global Biotechnology Report 2007," 139 biotechnology companies were operating in Israel, up from 25 in 1998.[161] Ernst and Young's findings in 2005 and 2007 on the absolute numbers of

[158] "Nemesysco, Ltd.—Voice Analysis Tools for Security and Commercial Use," http://www.nemesysco.com/ (accessed February 1, 2008).
[159] Denmark, Ministry of Foreign Affairs, "Biotechnology, Health, Pharmaceuticals and Rehabilitation Industries in Israel," September 7, 2007, http://www.ambtelaviv.um.dk/.../MarketOverview/SectorAnalysis/SundhedMedicoBiotech/Biotechnology/.
[160] Denmark, Ministry of Foreign Affairs, "Biotechnology, Health, Pharmaceuticals and Rehabilitation Industries in Israel."
[161] Israel, Ministry of Industry, Trade, and Labor, *Invest in Israel*, no. 22, April 2007, http://www.moit.gov.il/NR/rdonlyres/AD6A4775-5B39-4E98-8408-53F5FCE744BB/0/NEWSLETTERApril2007.pdf. For the 1998 figure, see California Technology, Trade, and Commerce Agency, Division of Global Economic Development, Office of

biotechnology companies placed Israel eighth in the world in 2005 and sixth in relation to European countries in 2007.[162] The great majority of the companies are very small, with fewer than 20 employees.[163] Biotech spending by companies in Israel amounts to 5 percent of total R&D spending in the business sector, compared to 7 percent in the United States.[164] From the mid-2005 to the end of 2006, Israeli biotechnology companies, often originally VC-backed, had a spate of offerings on the Tel Aviv Stock Exchange, raising more than US$127 million in IPOs.[165] In 2006, Israel also saw a major boost in VC investment in biotech, which was up to US$142 million from US$41 million in 2005, placing Israel in terms of VC-backing in the ranks of the major European biotech nations.[166] Israeli biotech companies in 2006 had 67 drug candidates in the pipeline, putting Israel, in a European comparison, in middle rank—in sixth place behind Germany (151 candidates), Britain (106) and France (85), but ahead of Sweden or Spain.[167] Currently, about 40 Israeli biotech companies generate revenues, and about 20 of these have products in the clinical stage.[168] That number of products in clinical phases puts Israel eighth on a European scale, behind such major players as the United Kingdom (246), Switzerland (97) and Germany (77).[169]

The Israeli biotech industry is well represented in many of the 10 or so application areas that can be said to make up the field.[170] Fields in which Israel is particularly active run the gamut

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Export Development, *Country Market Report, Israel: Market Opportunities in Biotechnology*, April 2003, 4. VC investments in Israeli biotech more than doubled from US$100 million in 1997 to US$240 million in 2001.

[162] Ernst and Young, "Beyond Borders Global Biotechnology Report 2007," http://www.ey.com/Global/assets.nsf/International/Industry_Biotechnology_Beyond_Borders_2007_Full/$file/BeyondBorders2007.pdf. See also Stacey Lawrence, "Biotech R&D Goes Further Afield," *Nature Biotechnology* 24, no. 9 (September 1, 2006): 1052. In the field of biotech, according to Ernst and Young, the United States dwarfs other countries, with 1,452 of the world's 4,275 companies in 2006, and 130,000 employees. In the same year, Europe as a whole had slightly more companies, at 1,621, but only about 39,000 employees. Canada had 465 companies, with 7,190 employees, and Asia had 737 companies, with 12,970 employees.

[163] Brigitte van Beuzekom and Anthony Arundel, *OECD Biotechnology Statistics, 2006*, (Paris: OECD, 2006), 96, http://www.oecd.org/dataoecd/51/59/36760212.pdf.

[164] Seven countries rank above Israel in their spending for business-sector biotechnology R&D as a percentage of total business biotechnology R&D. These countries spend as follows: Iceland, 51 percent; Denmark, 24 percent; New Zealand, 21 percent; Switzerland, 9 percent; the United States, 7 percent; and France, 6 percent.

[165] "Biotech: Recent VC Exit Trends," *IVCJ* (*Israel Venture Capital and Private Equity Journal*), June 2007, http://mofomojo.com/docs/pdf/IVCJ0607.pdf.

[166] Ernst and Young, 54.

[167] Ernst and Young, 48.

[168] Bernard Dichek, "Israeli Biotech Comes Into Its Own," *Nature Biotechnology*, 24, no. 4, April 2006, http://www.docoop.com/upload/File/Articles/Biotech%20in%20Israel%20Naturebiotech.pdf.

[169] Ernst and Young, 49.

[170] The areas often used in analyses include: human health; agriculture and aquaculture; environment; food processing; bioinformatics; natural resources; processes; testing and measurement; apparatus, article, component or material; composition, compound, cell, or molecule.

from therapeutic pharmaceuticals to diagnostics, agricultural biotechnology, and bioinformatics.[171] As in most countries with active biotech sectors, the therapeutics field dominates the Israeli biotech sector, as shown in table 4, accounting now for more than one-third of the companies.[172] In terms of sales, the major fields are, in order, therapeutic pharmaceuticals, with almost 70 percent; agrobiotechnology, with roughly 20 percent; and diagnostics, with about 4 percent (see table 4).

Table 4. Breakdown of Israeli Biotech Companies by Field

Field	# of Companies (as of 2004)	# of Employees (as of 2004)	% of Biotech Sales, 2000–2006
Agrobiotech	48	996	18–23%
Bioinformatics	6	300	NA
Biologicals	15	590	NA
Diagnostics	32	535	4–5%
Industrial	11	93	NA
Therapeutics	48	1,486	67–70%
Total	**160**	**4,000**	

Source: Israel, Ministry of Industry and Trade, Office of the Chief Scientist, as published in Ketaki Sood, "Israel's Flourishing Biotech Industry," May 10, 2004, http://www.larta.org/lavox/articlelinks/2004/040510_usisrael.asp.

In certain areas of biotech, Israel has as yet very limited sales but is in the vanguard, namely, in such fields as nanobiotechnology, predictive and personalized medicine, stem-cell therapies, and synthetic cannabinoid drugs.[173]

The Israeli biotechnology industry has launched a number of important drugs on the global market, including the four best selling prescription drugs of Israeli origin listed in table 5. In 2005 these four medicines, which include the world's two major therapies for multiple sclerosis—the blockbuster drugs Copaxone and Rebif—achieved more than US$3.5 billion in sales.

[171] Ketaki Sood, "Israel's Flourishing Biotech Industry," Larta Institute, May 10, 2004, http://www.larta.org/lavox/articlelinks/2004/040510_usisrael.asp.
[172] Michel Revel, "Biotechnology in Israel," Web site of Innovation Relay Centre Network—Israel, http://www.irc.org.il/biotech/option3.htm.
[173] Revel.

Table 5. Globally Important Prescription Medicines of Israeli Origin

Medicine	Developer	Function	2005 Sales
Copaxone	Weizmann Institute of Science/ Teva	A therapy for multiple sclerosis	US$1.2 billion
Doxil	Hadassah Medical Center/ Johnson & Johnson/Schering	Anticancer drug with proprietary delivery system	US$500 million
Exelon	Hebrew University/Novartis	Small-molecule cholinesterase inhibitor for Alzheimer's disease	US$470 million
Rebif	Weizmann Institute of Science/ InterPharm/Serono	Recombinant interferon-beta for multiple sclerosis and antiviral applications	US$1.3 billion

Source: Based on Bernard Dichek, "Israeli Biotech Comes Into Its Own," *Nature Biotechnology* 24, no. 4 (April 2006): 1, http://www.docoop.com/upload/File/Articles/Biotech%20in%20Israel%20Naturebiotech.pdf.

In 2005 Teva Pharmaceuticals, the world's largest generic drug maker and the only pharmaceutical heavyweight in Israel, brought to market its second prescription blockbuster (after Copaxone), Azilect–Rasagiline, a therapy for Parkinson's disease. Teva's introduction of this drug presaged its growing interest in biotechnology, an interest also demonstrated by the company's 2008 acquisition for US$400 million of the U.S. biotech firm CoGenesys, a specialist in the early drug development.[174] Teva continues to be a major investor in Israeli biotech companies.

The potential for the further growth of Israel's biotech sector is substantial, given the country's long-standing and growing R&D strength in the life sciences and related fields. Advanced research in biochemistry and the biotechnology sector is carried out at all seven universities, the four university-affiliated medical schools, the major hospitals, five colleges, and 10 specialized institutes. Two of these institutes, the Volcani Center and the Hebrew University's Faculty of Agriculture, do research in agricultural biotechnology and agrotechnology.

Because of growing interest in biotech among Israelis, university life sciences programs have been expanding in Israel. This is particularly true for new programs focusing on biotechnology.[175] Together, Israel's academic institutions host more than 800 life sciences

[174] Research-in-Germany, "Biotechnology in Israel," September 10, 2008, http://www.research-in-germany.de/coremedia/generator/dachportal/en/07__News_20and_20Events/Events_20-_20VA-Kalender/VDITZ/2008-10-09_2C_20Biotechnology_20in_20Israel.html.
[175] Lawrence.

research projects.[176] Advanced life sciences work is the focus of about 35 percent of all Israeli civilian research activities. Some 60 percent of all scientific publications in Israel are in agricultural sciences, biology, medicine, and related fields.[177] Two Israeli Universities—Hebrew University and the Weitzmann Institute—are among the world's top 10 universities in the number of patents registered per year.[178] In 2005 a poll conducted by *The Scientist* magazine found the Weizmann Institute to be the best research university in the world for life scientists.[179]

Most of Israel's biotechnology firms owe their existence to intellectual property that originated in Israel's universities or research institutes.[180] The first biotech start-ups in the 1980s, Biotechnology General and Interpharm—the sole players in Israel's private biotech sector for more than a decade—grew out of research done at the Weizmann Institute.[181] Interpharm, now a subsidiary of the Swiss company Serono, was a big winner with the multiple schlerosis drug Rebif interferon. By the early 1990s, Israeli policymakers recognized that bridging the gap between academic institutions, with their strong life sciences R&D performance, and the fledgling biotechnology industry would be a prerequisite for progress toward marketable biotech products. In order to facilitate the commercialization of academe's intellectual property, the government encouraged universities to set up their own R&D TTOs for the transfer of technologies into the biotech industry. In response, to take one example, Yissum, Hebrew University's TTO, created SBT, a start-up that deals with the engineering of skeletal and vascular tissue. SBT proved itself by developing a unique proprietary technology of ex-vivo (outside the body) tissue engineering using adult stem cells for the generation of tissue for transplants.[182] SBT has also developed methods for treating diabetes, cardiovascular diseases, and stroke, and a novel ex-vivo three-dimensional system for drug screening.[183]

In addition to TTOs, Israel offers other forms of support to the biotech industry. Since biotech was declared a national priority in 2000, it has been increasingly successful in securing

[176] ISERD, "Israel's R&D Capacity."
[177] Denmark, Ministry of Foreign Affairs, Embassy of Denmark, Israel, "Biotechnology," http://www.ambtelaviv.um.dk/en/menu/CommercialServices/MarketOverview/SectorAnalysis/SundhedMedicoBiotech/Biotechnology/Biotechnology.htm (accessed January 17, 2008).
[178] Denmark, Ministry of Foreign Affairs, Embassy of Denmark, Israel, "Biotechnology."
[179] Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel," 15.
[180] Prainsack and Firestine.
[181] Prainsack and Firestine.
[182] Hebrew University of Jerusalem, "Breakthrough in Creating Bio-Artificial Organs at Hebrew University-Hadassah Dental School," July 2, 2002, http://www.scienceblog.com/community/older/2002/F/20022744.html.
[183] Hebrew University of Jerusalem.

R&D grants from the grant program of the OCS of the MITL.[184] The OCS has also set up two specialized biotechnology incubators, including BioLineRx, that can accommodate the long lead times of product development in biotech by hosting biotech projects for longer periods than are available in general technology incubators.[185] Previously, biotechnology projects operated in the general incubators and were subjected to the same time demands as software and communications start-ups. The government's "Magnet" program, which brings together university-based scientists and already existing companies to work on basic research, has increasingly sponsored consortia relevant to biotech, for example, Da'at, on bioinformatics and protein modeling, and PharmiLogi, on forecasting systems aimed at developing drugs. Finally, the government has created national centers that provide infrastructures for the most advanced biotech technologies. The existing centers are for proteomics, including protein purification, microsequencing, and mass spectroscopy; transgenic animals; human genomic technologies; plant genome analysis and transgenic plants; robotic screening of molecular interactions; and bioinformatics, including networking for genome database mining, protein modeling, and drug design.[186]

In addition to receiving government support for biotech, which tends to target very early stages of projects, Israeli companies now have growing access to venture capital and to foreign partnerships, which can provide the substantial financial and organizational resources required to move beyond early-stage development. Life sciences investment funds have emerged that can finance the R&D for product development and clinical trials. Such funds include the Clal Biotechnology fund, a US$100 million VC fund supported by a consortium of international investors; BioMedica, a US$10 million fund; and a US$30 million fund, MAH, which is operated by a large agrochemicals concern, Makhteshim–Agan, and invests in plant genomics.[187] In addition, many VC funds that hitherto invested in electronics, telecommunications, and software have diversified their portfolios to include biotech companies.[188] Foreign investors and companies have also shown growing interest in Israeli biotechnology, establishing partnerships and making investments. The U.S. company Johnson & Johnson, for example, has invested in

[184] *ERAWATCH*.
[185] Dichek, 2.
[186] Dichek, 4.
[187] American-Israeli Cooperative Enterprise (AICE), "Biotechnology," http://www.jewishvirtuallibrary.org/jsource/Economy/biotech.html (accessed February 9, 2008).
[188] American-Israeli Cooperative Enterprise, "Biotechnology."

several Israeli biotech companies—Peptor, which has developed a drug to combat type-1 diabetes, and Neurosurvival Technologies—while multinationals Bayer and Baxter have invested in the Medica II VC fund.[189] In addition, in 2000 the U.S. firm Beckton Dickinson and Germany's Bayer AG became partners with the Israeli biotech companies GamidaGen and Omir through the BIRD Foundation, the U.S.-Israeli binational industrial R&D foundation set up in 1977.[190]

Biotechnology for Human Health

The increase in forms and levels of support for biotechnology in Israel has fueled the sector's growth and promises to aid companies in moving more expeditiously through the stages required to bring biotech products, such as pharmaceuticals, onto world markets. Currently, the majority of biotechnology companies remain at an early stage of development. However, numerous products, especially therapeutic drugs, are in the pipeline, and many have advanced beyond the threshold of early-stage R&D activity. The company Can–Fite, for example, has developed a technology that targets the A3 adenosine receptor for the treatment of cancer and autoimmune inflammatory diseases.[191] The company is currently in phase IIb clinical studies for the treatment of rheumatoid arthritis. The Pharmos company has developed a family of cannabinoid agonists that bind to a specific receptor, blocking pain. The first drug in the family, which has potential against neuroinflammatory diseases, has completed phase I studies.[192]

One notable growth area in which Israel is in the vanguard is stem-cell biotechnology. Israeli researchers have been at the forefront of efforts to isolate human embryonic stem cells (hESC) since 1998, when the world's first hESC lines were derived.[193] According to the October 2006 issue of the journal *Stem Cells*, Israel ranked second after the United States in *absolute* numbers of articles on hESC in peer-reviewed scientific journals up to the end of 2005.[194] In a

[189] American-Israeli Cooperative Enterprise, "Biotechnology."
[190] Ella Jacoby, "BIRD-F, US Co, to Invest $1.5 Mln in GamidaGen of Israel: GamidaGen and Beckton-Dickinson Will Develop a Genetic Disease Diagnosis System," *Globes* [online], January 20, 2000, http://www.globes.co.il/DocsEn/did=381849.htm.
[191] Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel,"13.
[192] Dichek, 4.
[193] Dichek, 4.
[194] Judy Siegel-Itzovich, "Israeli Human Embryonic Stem Cell Research is 2nd in World," *Jerusalem Post Online Edition*, October 5, 2006, http://www.jpost.com/servlet/Satellite?cid=1159193379030&pagename=JPost%2FJPArticle%2FshowFull.

ranking by quality of the 308 articles covered, four by Israeli researchers were placed among the top 11. In *per capita* terms, according to a German study that covers the years 2000–4, Israel was the world's leading publisher of hESC research, followed in rank by Sweden, Switzerland, the Netherlands, Austria, and the United States.[195]

Although controversial elsewhere, embryonic stem-cell research, as well as related activities such as prenatal genetic testing and human cloning, have aroused no significant public debate in Israel.[196] The government, especially the Ministry of Industry, Trade, and Labor and the Ministry of Science and Technology, supports stem-cell research both through funding and through policies that are non-restrictive, save for banning human cloning. Unlike the United States, for example, Israel does not restrict the stem-cell lines on which researchers can experiment.[197] Able to operate within a liberal and supportive regulatory framework, some 10 stem-cell technology start-ups have been founded, some of which are already involved in clinical trials.[198] Two of these start-ups seem to be in the lead in the world's quest to develop a stem-cell therapy for Parkinson's disease (see table 6). BrainStorm Cell Therapeutics uses autologous bone marrow–derived adult stem cells, and Cell Cure employs a human embryonic stem-cell technology.[199] BrainStorm is on the verge of clinical trials, having shown in pre-clinical trials that its therapy can reduce the symptoms of Parkinson's in mouse models. Cell Cure has shown the efficacy of embryonic stem-cell–derived dopaminergic cells, which are used to treat Parkinson's disease, in animal models.

Table 6. Notable Israeli Stem-Cell Companies

Company	**Research Aim**
BrainStorm Cell Therapeutics	Dopaminergic cells to treat Parkinson's
CellCure Neurosciences	Dopaminergic cells to treat Parkinson's
Gamida Cell	Stem-cell expansion technologies
Pluristem Life Systems	Placental stem-cell technology for improving bone marrow transplantation

Source: Bernard Dichek, "Israeli Biotech Comes Into Its Own," *Nature Biotechnology* 24, no. 4 (April 2006), http://www.docoop.com/upload/File/Articles/Biotech%20in%20Israel%20Naturebiotech.pdf.

[195] "Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel," 14.
[196] Prainsack and Firestine.
[197] Siegel-Itzkovitz.
[198] "Israel, Ministry of Industry, Trade, and Labor, "Life Sciences in Israel," 13.
[199] Dichek, 4.

Other subsectors within biotechnology in which Israel excels are two areas that combine life sciences research and information technology, the interdisciplinary technologies of bioinformatics and proteomics. The new field of bioinformatics creates computational tools that can analyze biological data in vast quantities, specifically, genomic information, and proteomics creates tools capable of identifying proteins through human tissue analysis. Both fields can benefit from Israel's high levels of expertise in mathematics, physics, and computer sciences. The company Compugen, for example, has capitalized on the skills of its founders, three computer experts from a military intelligence unit, to become a leading company in bioinformatics and proteomics. The company, founded in 1993, creates biomathematical tools to sift through the huge amounts of molecular information accumulated by the Human Genome Project, and to discover candidate compounds for new pharmaceuticals. Compugen's customer base includes the international pharmaceutical concerns Merck, Eli Lilly, SmithKline Beecham Pharmaceuticals, Millennium Pharmaceuticals, and Novartis.[200]

In addition to the strengths of Israel's biotech sector in developing pharmaceuticals and computational solutions, Israeli companies have a substantial track record in developing medical equipment and devices that utilize breakthrough technologies, for example, sophisticated imaging and surgical tools. In the 1990s, Elscint pioneered in advanced medical imaging tools, and Lumenis grew to be the world's largest maker of laser instruments for surgery of several types.[201] One recent breakthrough, which made international headlines, is a diagnostic imaging device consisting of an encapsulated miniature camera. Once swallowed, the tiny camera transmits images of the upper gastrointestinal tract to a screen from which doctors can diagnose disorders, thereby eliminating the need for invasive diagnostic surgery. The idea for this capsule device, produced by Given Imaging, came from the military, specifically, from a missile scientist who drew upon his development work for the 3,000-pound Popeye missile, a missile that can pinpoint a small target from standoff ranges of up to 100 kilometers.[202]

Another invention involving a swallowed device is an oral drug-delivery technology, a capsule containing a mini-accordion with a drug inside. Produced by Intec Pharma, a start-up

[200] American-Israeli Cooperative Enterprise, "Biotechnology."
[201] Nechama Goldman Barash, "Facets of the Israeli Economy—Biotechnology," Israel, Ministry of Foreign Affairs, November 1, 2002, http://www.israel.org/MFA/MFAArchive/2000_2009/2002/11/Facets%20of%20the%20Israeli%20Economy-%20Biotechnology.
[202] American-Israeli Cooperative Enterprise, "Biotechnology."

founded in 2000, the capsule dissolves after ingestion, the accordion opens, and the drug is released in a gradual, controlled manner.[203]

Agrobiotechnology and Agrotechnology

In addition to pursuing biotech work focused on human health, Israel is a prominent player in the field of agrobiotechnology. A significant part of Israel's advanced R&D in the life sciences has always been and continues to be related to agriculture. Such R&D supports Israel's intensive agricultural production systems, including its extensive greenhouse production, which grows high value-added produce and flowers for export, particularly to the European market.[204] Israel has been known for innovation in agriculture since the founding of the state, having had its first major R&D-based success with the invention of the drip irrigation system.[205] The system, now computer-controlled, is in use worldwide and across half of Israel's agricultural land, saving huge quantities of water. Israel is also known for R&D-based innovation in greenhouse technology, agromechanical equipment, and plant genetics. Recently, Israel has used the techniques and tools of biotechnology to accelerate the development of improved strains of plants and animals. Through the use of marker genes and the development of new hereditary characteristics, Israel creates agrobiotechnology products that make up roughly 20 percent of sales in Israel's biotech industry. The bulk of these sales are of genetically engineered hybrid seeds produced by companies such as Hazera, Rahan Meristem, Vitality, and Zeraim Gedera.[206] Israeli agrobiotech companies also produce animal vaccines (e.g., the company Abic), insects to combat plant parasites (BioBee), and cellulose-based technologies.[207]

Agricultural research in Israel is carried out by the public and private sectors, both of which receive various kinds of government support. The government provides about 85 percent of funding, while other resources are provided by the private sector and binational and international funds. In the public sector, two ministries are involved in financial, organizational, and other support for research in agriculture: the Ministry of Agriculture and Rural Development

[203] Karin Kloosterman, "Israel's 'Accordion Pill' Unfolds According to Plan," July 10, 2005, http://www.israel21c.org/bin/en.jsp?enScript=PrintVersion.jsp&enDispWho=Articles%5El1035.
[204] European Commission, "Israel: Overview of Science Policy and Strategy," http://ec.europa.eu/research/agriculture/scar/index_en.cfm?p=1_il (accessed March 7, 2008).
[205] Gerald Ondrey, "Membrane Technology Enhancements Make Water More Affordable at World's Largest Desalination Plant," *Chemical Engineering* 112, no. 12 (November 2005): 15 (via Proquest).
[206] Ondrey, 15.

(MOARD) and, to a lesser extent, the MOST.[208] The chief scientist of MOARD bears the primary responsibility for determining Israel's research goals in agriculture and for funding research and monitoring research performance. A unit attached to MOARD, the government research institute Agricultural Research Organization, carries out the vast majority of agricultural research in Israel.[209] Research in agriculture is also carried out by several universities, most notably, Hebrew University, in its Faculty of Agriculture, Food, and Environmental Sciences.[210] In addition, Israel has a number of regional or specialized research institutions, which often focus on the unique agro-climatic conditions of peripheral areas. The Upper Galilee Center for Knowledge (MIGAL) and the National Center for Mariculture are two such institutions.[211] Within the private sector, manufacturers of agriculturally related products (e.g., fertilizers, seeds, pesticides, and irrigation equipment) perform research. This in-house private-sector research receives support from the OCS of the MITL.[212]

Nanotechnology and Nanoelectronics

Israel already has a notable track record in the young field of nanotechnology, the interdisciplinary field devoted to controlling matter and fabricating devices on the scale of one-millionth of a millimeter. Since the bursting of the high-tech bubble, Israeli policymakers have designated nanoscience and nanotechnology R&D as top priorities, along with biotechnology.[213] They look to nano-enabled and nano-enabling technologies to bolster the future competitiveness of many Israeli products and applications over a broad range of industries. The Philadelphia-based Institute for Science Information (ISI), the foremost publisher of scientific bibliographic and citation data, has included Israel among the top 15 most effective countries in producing nanotech-related knowledge and technologies. Between 1995 and 2006, according to figures maintained by the ISI Web of Knowledge, the intellectual property yield of nanoscience and nanotechnology research in Israel has been substantial, with more than 100 patents and about

[207] Revel.
[208] *ERAWATCH*.
[209] ARO consists of six research institutes: plant science; animal science; soil, water, and environmental science; agricultural engineering; technology and storage of agricultural products. See Agricultural Research Organization of Israel Web site, http://www.agri.gov.il.
[210] See Hebrew University of Jerusalem Web site, http://www.huji.ac.il.
[211] See Israel Oceanographic and Limnological Research Web site, http://www.ocean.org.il.
[212] Israel, Ministry of Agriculture and Rural Development, Office of the Chief Scientist Web site, http://www.science.moag.gov.il/forms/AnnualCall.doc.

2,000 publications.[214] A study sponsored by the European Commission some years ago also highlighted Israel's nanotech strengths. According to the study, the number of Israeli nanotech patents and publications, calculated on a normalized basis, ranked third and second in the world in 2002, respectively, after Germany and Switzerland.[215] On the same normalized basis, the U.S. ranked sixth for patents and fourteenth for publications.[216]

The largest share of Israeli nanotech research is currently conducted with government support in university research centers. Beginning with the Technion in 2005, six of Israel's universities have now established nanotech research centers. The first of these and one of the world's largest, the Russell Berrie Nanotechnology Institute at the Technion, was started with an investment of US$52 million, half in Israeli or U.S. government matching funds and half donated by a U.S. foundation, the Russell Berrie Foundation of New Jersey.[217] The Technion center expects to raise an additional US$38 million by 2010, mostly from other American donors. That center and each of the other new university-based nanotech research centers promotes interdisciplinary work, while retaining its own emphasis on nanosciences and nanotechnology programs (see table 7). Led by the Technion, Israel's six universities have accommodated many new researchers in nanotechnology studies. Researchers reporting work in or related to nanotech now number about 330, a figure that has doubled since 2002 and is expected to continue growing rapidly.[218]

To support this growth and, particularly, to promote the commercialization of nanotech work, in 2001 Israel created the National Nanotechnology Initiative (INNI), Israel's policy and support organization for nanotech. A shared initiative of Israel's Forum for National Infrastructures for Research and Development (TELEM) and the MITL, INNI is responsible for setting the country's national priorities and planning programs for advancing nanotechnology. INNI also allocates government funding for the improvement of laboratory infrastructure and

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[213] *ERAWATCH*.
[214] "Israel Steps Up Nanotech Funding," *Science Business*, September 19, 2006, http://bulletin.sciencebusiness.net/ebulletins/showissue.php3?page=/548/2025/6277.
[215] See Israel National Nanotechnology Initiative (INNI) Web site, http://www.nanoisrael.org/nanoisrael.asp. See also *Nanotech Advantage Israel*, November 2003, http://advantage.bobrosenbaum.com/issues/nanadvant_nov03.htm.
[216] *Nanotech Advantage Israel*.
[217] Nanotech Wire, "Nanotech Center: A Model Project," *NanoTechWire.com*, February 9, 2005, http://www.nanotechwire.com/news.asp?nid=1581.
[218] INNI "Israeli Nanotech Research Centers, 2006," http://www.nanoisrael.org/download/surveys/israel_nanocenters_map_2006.gif.

promotes international collaboration in nanotech development and commercialization. Another key task of INNI is periodically to report on the researchers in particular research areas, the number of citations of publications in specific fields, the number of patents sought, the level of research funding available, and the number of firms pursuing nanotech work.[219]

Table 7. Israeli University-Based Nanotech Research Centers

Institution	Center	Focus
Bar Ilan University in Ramat Gan	Bar Ilan Center for Advanced Materials and Nanotechnology (BICAMN)	Coordinates the activities of 18 research groups in chemistry, physics, and the life sciences.
Ben Gurion University of the Negev in Beer-Sheva	Ilse Katz Center for Meso and Nanoscale Science	Focuses on fundamental research of nanoscale materials and the manipulation of matter at reduced dimensions.
Hebrew University of Jerusalem	Harvey Krueger Center for Nanoscience and Nanotechnology	A multidisciplinary center that promotes interaction among the university's scientists in physics, applied and life sciences, and computer science and engineering.
Technion Israel Institute of Technology in Haifa	Russell Berrie Nanotechnology Institute	Unifies the work of more than 100 research faculty in 12 disciplines and supports existing centers in microelectronics, electron microscopy, and surface characterization. The Institute will also provide infrastructure for new centers in nanoelectronics and nanobiotechnology.
Tel Aviv University	Tel Aviv University Research Institute for Nanoscience and Nanotechnology	An interdisciplinary center serving faculties of engineering, exact sciences, life sciences, and medicine. The institute supports fundamental and applications-level research, nanofabrication, modeling, and characterization.
Weizmann Institute of Science in Rehovot	Braun Center for Submicron Research	A highly specialized facility enabling the design, material growth, fabrication, and characterization of mesoscopic electronic semiconductor systems.
Weizmann Institute of Science	Kimmel Center for Nanoscale Science	Intends to help establish critical research links between molecular biology and nanoscale science.
Weizmann Institute of Science	Goldschleger Center for Nanophysics	Supports theoretical and experimental research in nanophysics.

Source: Based on Israel National Nanotechnology Initiative (INNI), "Israeli Nanotech Research Centers, 2006," http://www.nanoisrael.org/download/surveys/israel_nanocenters_map_2006.gif.

[219] INNI, "Industry Sectors," http://www.nanoisrael.org/nanoil_industry.asp.

A 2007 nanotech R&D survey by INNI, an update of studies conducted in 2002 and 2005, identifies more than 80 Israeli firms engaged in developing nanotech-related products.[220] According to the study, these firms include more than a dozen Israeli corporations already engaged in nanotech-related R&D, either independently or in collaboration with academic or industrial partners.[221] Of the 80 or so companies involved in nanotech, about 65 are start-ups with core missions devoted entirely to nano-enabled or nano-enabling products. D&A High-Tech Information Ltd., an industry analysis firm based near Tel Aviv, maintains a very complete compendium of, and links to, nano-industries and companies in Israel, including directories of the companies and researchers involved in various sectors of the industry.[222] A representative list of Israeli companies involved in nanotech research is shown in table 8.

Table 8. Nanotechnology Beyond the Universities

Company	Area of Nanotech Activity
Advanced Nanoparticles Ltd.	Contrast agents for MRI and ultrasound imaging
Applied Nanomaterials Ltd.	Solid lubricants
B.G.Polymers Ltd.	Acrylic polymers for the building and paint industry
Cerel Ceramic Technologies Ltd.	Electrophoretic deposition (EPD)
Nanolayers Ltd.	Monolayers epitaxy growth
Nanomotion Ltd.	Miniature piezo-ceramic motors and positioning systems
Nanonics Imaging Ltd.	Microscopy, telecom, and semiconductors characterization
Nano-Or Technologies Ltd.	Inspection products
Nanopowders Industries Israel Ltd.	Metal powder production
Nanosize Ltd.	Advanced material processing
Newgal Ltd.	Synthesis of diamond and diamond dust
PCB Laser Ltd.	Semiconductor wafers grown by molecular beam epitaxy
Sol-Gel Technologies Ltd.	Encapsulated actives for cosmetic, oral care, and consumer products
Solubest Ltd.	Enhancing the potential of poorly soluble drugs

Source: Based on Israel–Europe R&D Directorate for the EU Framework Program (ISERD), "Israel's R&D Capacity: A Promising Land," http://www.iserd.org.il.

Anticipating that nanotech will be increasingly competitive in the next 10 years, the Israeli government offers various forms of both organizational and financial support. Through "Magnet," the program of the OCS of the MITL to promote university/business research cooperation, the government set up the Nano Functional Materials (NFM) consortium. A

[220] INNI, "2007 Nanotech Survey," http://www.nanoisrael.org/survey_home.asp.
[221] INNI, "Established Firms," http://www.nanoisrael.org/player_estabs.asp.

consortium of 13 companies and 12 academic research groups in Israel, the group seeks new ways to fabricate and use nanoparticles in industrial processes and products.[223] Other efforts by the Israeli government to promote nanotechnology include the publication of ongoing projects that have strong business potential provided that they receive additional investment, collaborators, and other support. One list of promising opportunities, published by the Organization for the Promotion of Trade, Israel–Netherlands (OPTIN), includes numerous projects in nanobiotechnology (see table 9). The projects listed, all of which are patented, represent various stages of development, ranging from early-stage development in university projects to full-fledged company development efforts.

Table 9. New Projects in Nanobiotechnology

Biological nanocomputer
Biosensors as a diagnostic tool
Capacitor-based single-molecule motion detectors
Enzyme-binding proteins for functional nanostructures
Fabricating nanoscale objects within novel types of discrete peptide nanotubes
Fabrication of nano-photoswitches, photosensors, and photocells by self-assembly on solid gold surface
G4 DNA organic nanoconductors
Immediate, topical-drug delivery system utilizing an injection mechanism found in sea life
Making insoluble active compounds soluble
Molecular devices and smart materials based on a novel molecular architecture
Nanotechnology-based skeletal tissue engineering and gene therapy
Optical sensors for detecting chemical and biological substances
Quick and painless mechanisms for topical drug delivery into human patients
Rapid bioelectronic HIV-protease drug resistance test and drug-potency screening for AIDS patients
Recombinant antibody chips
Self-assembly of nanoscale protein scaffolds
Self-assembly of very short peptide fragments, the building blocks of bionanomaterials
Structure, assembly, function, and dynamics of molecular machines
Technology for synthesizing specific, stable, and potent nucleic acid–based polymers
Source: Based on "New Projects in Nano-Biotechnology," *The Life Sciences Project Bulletin*, no. 17 (October 2003), http://www.optin.nl/projec/bulletin17.html.

[222] D&A Hi-Tech Information, Ltd., Web site, http://www.dainfo.com/HPage.aspx.
[223] Nano Functional Materials Web site, http://www.nfm.org.il/.

Israel is also pursuing a matching-fund model of financing to increase resources available to researchers in the field. In November 2006, it was announced that Israeli nanotech centers would receive US$230 million of funding through 2011 via expansion of a "funding triangle" donation program.[224] In the program, private donations to Israel's university-based nanotech research centers will be matched by both the universities and the Israeli government, thus tripling the donation's value. In addition to matching funds, the Israeli government will also provide more than US$8 million for nanotech-related equipment purchases and for advanced research projects in water treatment using nanotechnology.

The funding triangle donation matching program will give preference to research in areas considered to have the strongest potential for Israeli breakthroughs and those that can lead to commercialization. The areas identified as strategic are: nanomaterials, nanobiotechnology/ medical, nanoelectronics/optics, and nanotech for applications in water treatment and alternative energy. Israel's research applications and activity levels in these areas of nanoresearch are summarized in table 10. The areas of nanotech research identified as strategic are the focus of Israel's nanotech companies, both start-ups and established firms. However, as in other leading nations in nanotech, Israeli nanotech is in the early stages of commercialization and still needs substantial additional support to ensure growth.

Security Applications of Nanotech: The Bionic Hornet and Other Microrobots

One area in which Israeli R&D in nanotechnology is expected to yield near-term results is in military applications. Israel has underway numerous military and security-related nanotech warfare and security programs. Within the last several years, the vice prime minister of Israel charged a selected group of Israeli security, high-tech, and academic experts with developing state-of-the-art devices based on nanotechnology. One project emerging from this initiative is the so-called "bionic hornet," essentially a miniature remote pilotless flying vehicle (RPV) or unmanned aerial vehicle (UAV) the size of a hornet. According to a report in November 2006, Israel has a five-year plan to use nanotechnology to develop these robots and will invest US$240 million in nanotechnology research, while seeking further millions from international

[224] Nano Science Works, "Israel Broadens Matching Funds Program for University-Based Nanotech Research Centers, " September 2006.

Table 10. Israel's Nanotech Priority Areas and Applications

Discipline	Applications of Nano-Related Research	Level of Activity
Nanobio and Nanomedical Science	*Bio*–Biosensors, new biotechnologies for synthesis and analysis; functionality detection; molecular computing; molecular electronics; nanoscale arrays; integrated bio-chips (integrating Nano and MEMS). *Medical science*–Field sensor and detoxification for nerve gas and viruses; novel drug therapies, including gene therapy and peptide and protein delivery systems; detoxification of blood via interaction with nanoparticles; selective treatment and smart medicines; drug or vaccine release.	Current research in the bio/medical area is increasingly likely to be commercialized and marketed. Nanobiotech capacity benefits from growing dedicated pools of venture funding.
Nanoelectronics and Nano-Optics	Higher-speed devices; high-density low-cost arrays; denser and faster low currents and electronics with larger memories; sensors; and SI-based lasers. Integrated optoelectronics on Si chips; tunable LEDs and lasers; optical switches and logic gates; infrared detectors; optics based on nanostructures.	More than 80 percent of Israel's nanotech researchers are engaged in disciplines that contribute to nanoelectronics and photonics.
Nanomaterials	Produced through chemical processing, harder, self-repairing, and environmentally friendly materials; novel coatings that are super-hard and wear-resistant; novel thin films with unique properties such as high magnetization and improved adhesion; high-performance nanocomposites, super-lubricants, and high-performance smart ceramics.	Among the nano-related disciplines, Israeli chemistry nanoresearch is currently funded at the second highest level, after basic scientific research.
Nanowater	Nanomembranes, nanofiltration, and other nanotechnologies used in water remediation. Applications in water treatment and alternative energy.	Israel's filtration and membrane R&D remains strong, with a national research capacity exceeding that of many larger nations.

Source: Based on Israel–Europe R&D Directorate for the EU Framework Program (ISERD), "Israel's R&D Capacity: A Promising Land," http://www.iserd.org.il.

investors.[225] The rationale for such miniaturized UAVs is that they could in some cases accomplish missions that require stealth or be used in missions for which it would not be economically feasible to use and risk US$100 million aircraft. The "bionic hornets" will be used to collect information and take photographs. Capable of flying through narrow and otherwise inaccessible urban places without attracting attention, the bionic hornet could even be used for lethal missions against lone individuals or other small targets, seeking them out and launching

[225] "Cornell's Self-Healing Robot and Israel's Miniaturized Killing Machines," Artificial Intelligence and Robotics Web site, November 19, 2006, http://smart-machines.blogspot.com/search/label/bionic%20hornet.

miniature rockets at them.[226] In a battlefield situation, the idea would be to create a swarm of flying microrobots to act like micro-kamikazes.[227] Israel's developers of this potentially lethal nanotech believe they can have a functional prototype within three years. Their stated timeframe matches that of U.S. developers of similar tiny flying robots. According to Robert Wood, the founder of Harvard's Microrobotics Lab, partially funded by the Defense Advanced Research Projects Agency (DARPA), his robotic creatures could be flying around the lab on their own in the next five years, and possibly be ready for the real world in another five years.[228]

Besides the bionic hornet, Israel's nanotechnology researchers are also working on other security-related nanotech ideas, for example, miniature sensors that can be distributed in public places to detect suicide bombers by sensing the scent of explosive material, heat, or weight. Israel is also reportedly developing "super gloves" that would give the wearer "bionic man"–type strength.[229]

DNA Computing with Possible Medical Applications

An area of nanotechnology-related research in which Israeli researchers have repeatedly made international headlines is DNA or molecular computing, the use of biomolecules to execute computations.[230] A team of researchers led by mathematicians/computer scientists Ehud Shapiro and Yaakov Benenson at the Weizmann Institute experimentally demonstrated that they could create a biomolecular device—a device made of DNA and DNA-manipulating enzymes—that could execute multiple computational steps without outside mediation.[231] The ultimate applications they envision for their approach to DNA computing include medical uses, in particular the vision of a "doctor-in-a cell" or a "smart drug."[232] A biological computer,

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[226] DPA, "Israel Developing 'Bionic Hornet' for Spy Work," *Science News*, November 17, 2006.
[227] David Crane, "Nanotechnology Goes Lethal: Israel Developing 'Bionic Hornet' to Target and Kill Enemy Combatants," *Defense Review*, November 17, 2006, http://www.defensereview.com.
[228] Suzanne Taylor, "What's That Buzzing?" *Maclean's*, December 3, 2007, 48 (via Proquest).
[229] "Bionic Hornets: Israel Looks at the Next Generation of Warfare," *Spiegel Online*, November 17, 2006, http://www.spiegel.de/international/0,1518,druck-449171,00.html.
[230] Carlo C. Maley, "DNA Computing and Its Frontiers," in *Molecular Computing*, ed. Tanya Sienko, Andrew Adamatzky, Nicholas G. Rambidi, and Michael Conrad, 153–87 (Cambridge, Massachusetts: The MIT Press, 2003).
[231] Ehud Shapiro, "A Mechanical Turing Machine: Blueprint for a Biomolecular Computer" (paper presented at the Fifth International Meeting on DNA Based Computers, Massachusetts Institute of Technology, June 14–15, 1999), http://www.weizmann.ac.il/udi/press.
[232] Yaakov Benenson, Rivka Adar, Tamar Paz-Elizur, Zvi Livneh, and Ehud Shapiro, "DNA Molecule Provides a Computing Machine with Both Data and Fuel," *Proceedings of the National Academy of Sciences* 100 (March 4, 2003): 2191–96, http://www.pnas.org/cgi/content/full/100/5/2191.

according to Shapiro, could in the future operate in the human body, interact with the body's biochemical environment, and sense irregular, harmful biochemical changes in the tissue.[233] After detecting or "diagnosing" anomalous changes by sensing the presence or absence of particular disease indicators, the computer might even be able to decide what therapeutic molecule or drug to synthesize and release in order to correct the anomaly and treat or prevent disease.[234] Such a diagnosis and drug-delivery sequence could have major applications in the biological and pharmaceutical fields.[235]

To date, the Shapiro–Benenson team's biomolecular computer has been demonstrated only in a test tube, where different concentrations of RNA and DNA molecules simulate the different biological environments to which the biomolecular automaton's components react.[236] The team's goals at present include making the automaton carry out computation and act inside a living cell.[237] The researchers, however, are still far from applying their device inside cells, let alone in living organisms. The goal of an in vivo (living cell) as opposed to in vitro (test tube) operation poses formidable challenges, including delivering the automaton into a cell. Another hurdle is showing that the automaton can work without the cell's molecules and activities disrupting computational steps or the computer's components affecting cellular behavior in unforeseen ways. The team considers their research on medical applications to be in its early stages and actual uses in the body to be a long way, perhaps decades, off. They are also not sure that their particular automaton design will prove the most fruitful approach to the doctor-in-a-cell vision.[238] Other Israeli scientists are engaged in related research. One such scientist is Ehud Keinan, who divides his time between the Technion, where he founded and heads the Institute of Catalysis Science and Technology, and the Scripps Research Institute in La Jolla, California.

[233] "Biochemistry, Tiny Computing Machine Fueled by DNA," *Life Science Weekly*, March 17, 2003, 4.
[234] Roger Highfield, "Healing Computer to Work in Body," *The Daily Telegraph*, April 29, 2004, 4, http://www.telegraph.co.uk.
[235] Allison Kaplan Sommer, "A Doctor in a Cell; Israeli Scientist Ehud Shapiro Has Created a Tiny Computer that Fits Into a Drop of Water—And It Can Cure What Ails You," *Inside* 25, no. 3 (Fall 2004): 45.
[236] Ehud Shapiro and Yaakov Benenson, "Bringing DNA Computers to Life," *Scientific American* 294, no. 5 (May 2006): 44–52.
[237] Yaakov Benenson, Binyamin Gil, Uri Ben-Dor, Rivka Adar, and Ehud Shapiro, "An Autonomous Molecular Computer for Logical Control of Gene Expression," *Nature* 429 (May 27, 2004): 423–29, http://dx.doi.org/10.1038/nature02551.
[238] Shapiro and Benenson.

Keinan, combining research on DNA computing and nanotechnology, works on more powerful versions of Benenson-like DNA automata that use DNA chips.[239]

Water Treatment Using Nanotechnology

In addition to nanotechnology applications in the medical and military fields, Israeli researchers are pursuing applications of nanoresearch in water treatment. The government offers support for such research through a program initiated in 2004, the NATAF program, "Nano Technologies Applied to Water Purification." The program targets researchers who have not previously worked in the field of water technologies.[240]

"Cleantech": Water, Alternative Energy, and Environmental Technologies

Israel's potential for R&D-based innovation in the environment-related technology sector—commonly called "cleantech" by Israeli sources—is substantial and is increasingly being tapped. Because of the geographic and climatic conditions in Israel—the aridity, the abundance of sun, and the lack of oil resources—the country has vast experience in developing water and solar energy technologies. It also has some track record in other fossil-fuel alternatives, such as geothermal energy, as well as in waste/pollution and resource management.

According to an Israel Export and International Cooperation Institute report, there are currently 500 companies in the cleantech field in Israel.[241] By 2006, recognizing the profit potential of cleantech, six VC funds dedicated to the cleantech sector had emerged locally, raising funds worth more than US$300 million.[242] According to a recent report by New Energy Finance (NEF), Israel can already boast a number of the world's leading clean-energy companies. They include the publicly traded Ormat Technologies (with a market capitalization of US$1.35 billion), which specializes in geothermal power, and Medis Technologies (with a

[239] National Academies Press, Board on Global Health, and Development, Security, and Cooperation, "An International Perspective on Advancing Technologies and Strategies for Managing Dual-Use Risks: Report of a Workshop (2005)," http://darwin.nap.edu/books/0309096820/html/64.html.
[240] European Community Research and Development Information Service (CORDIS), "Nataf—Water Improvement by Nano Technologies," http://cordis.europa.eu/erawatch/index.cfm?fuseaction=prog.document&uuid=4971C406-D3E5-FCD9-5B1D1324BAF70051.
[241] D&A Hi-Tech Information Ltd., "Israel Cleantech Knowledge Portal," http://search.dainfo.com/cleantech/Template1/Pages/StartSearchPage.aspx.
[242] Jennifer Kho, "Israeli Clean Energy Set to Boom," *Red Herring*, November 26, 2006, http://www.redherring.com/Home/19910.

market capitalization of US$711 billion), which specializes in direct liquid fuel-cell technology.[243] In 2008 D&A Hi-Tech Information Ltd. identifies 156 companies in water technologies, including alternative technologies and water efficiency; 171 firms in energy, including alternative energy and energy efficiency; and 79 companies in environmental activities relating to air, soil, and nonperishable materials.[244]

Water Technologies

Among the cleantech areas in which Israel is active, water technologies loom large. Thanks to its own water scarcity and distribution problems, Israel has always made the optimization of water use a priority. Israel is the world's number-one water recycler, with a 75 percent water-recycling rate, far ahead of the 12 percent rate of the second largest recycler, Spain.[245] Israel is a leader in an array of water technologies—technologies for irrigation, for purification and reclamation, including saltwater desalination, and for water security. By the end of 2006, the number of water-technology companies in Israel grew to about 270. The growing industry's exports in 2006 increased to US$900 million, up by 21 percent over 2005.[246] Israel established its reputation as a leader in water technologies in the early 1960s, when it invented drip irrigation. Israel now uses drip irrigation on 60 percent of its agricultural land, compared to 6 percent in the United States. Israel exports more than 80 percent of its irrigation solutions, and, according to *Business Week*, Israeli companies control half of the estimated US$1–$1.5 billion global market for drip-irrigation solutions.[247]

Israel's commercial water sector, which was originally based on agriculture-related companies, has expanded its R&D activities to the additional subsectors of desalination and recycling, transport, and security. In 2005 Israel opened the world's largest saltwater reverse osmosis water (SWRO) desalination plant in Ashkelon on the Israeli coast. The US$250 million facility, built by IDE, a leading Israeli desalination company, produces 100 million cubic meters of potable water per year at the cost of about US$0.57 per cubic meter, the lowest cost in the

[243] Kho.
[244] D&A Hi-Tech Information Ltd., "Israel Cleantech Knowledge Portal."
[245] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech (Novel Efficient Water Technologies), "Water: The Israeli Experience," http://www.cambici.com.br/download/Israel-newtech-interim-brochure060907.pdf.
[246] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech.
[247] Neal Sandler, "Waterworks for the World?" *Business Week*, December 30, 2005, http://www.businessweek.com/technology/content/dec2005/tc20051230_495029.htm.

world.[248] In addition to the Asheklon plant, Israel has 31 small desalination plants in southern Israel, which generate 26 million cubic meters of water per year from both seawater and underground geothermal water. Israel's water commission anticipates that Israel will consume 20 percent desalinated water by 2010. Beyond the local market, Israeli companies have built hundreds of Israeli-made desalination plants throughout the world, in Africa, Asia, Europe, and South America, including China's largest desalination facility, a US$119 million facility built in 2007 by IDE.[249]

In addition to its work in desalination, Israel is also innovative in water recycling. Israeli research has produced sophisticated technology for recycling wastewater, including advanced techniques for using magnetic particles to separate organic toxins, electro-flocculation to speed settling, laser-based analysis to detect microscopic solids, ultra-violet purification to disinfect, and others.[250] Through the combined techniques, Israel recycles 200 million cubic meters of wastewater per year.[251]

In another subsector of water technology, water security technology, Israel's Technion is carrying out research, financed by the North Atlantic Treaty Organization, to devise mathematical models of water flow that can guide the strategic placement for monitoring stations. The Technion is also doing related research to develop technology that can neutralize chemical and biological contaminants in water. Hebrew University is currently researching models for safety and security in urban sewage models as part of the EU R&D Framework, an ongoing series of multi-year programs through which the EU funds transnational R&D in Europe.[252]

Israeli R&D in water technologies has strong support in Israel's academic institutions, cooperative agricultural bodies, and government agencies, as well as the backing of the VC industry. The universities have traditionally dedicated major resources to R&D in order to find techniques to stretch the country's limited water supply. Currently, the Department of Soil and Water Sciences at the Hebrew University's Faculty of Agriculture continues to refine drip irrigation and the efficient utilization of brackish water. Water research institutes at Ben Gurion

[248] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech.
[249] IDE Technologies, Ltd., "IDE Signs Contract to Build China's Largest Plant," July 30, 2007, http://www.ide-tech.com/News_item.asp?iid=15298&pid=1599&ppid=1489&z=2&p=1.
[250] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech.
[251] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech.

University of the Negev focus on all aspects of water-technology research, ranging from groundwater production and desalination technologies to treatments for marginal water sources, and the water research institute at the Technion in Haifa focuses on interdisciplinary R&D in water science, technology, engineering, and management.[253] In addition to the university institutes, Israel has a number of water-dedicated technological incubators to accelerate the growth of water-technology start-ups, including the Kinarot Jordan Valley Technological Incubator, which was acquired in 2006 by Canadian businessman Ron Stern, and the Ashkelon Technological Incubator (ATI), which currently has eight companies in the incubation stage.[254] In addition, in June 2006, the government, recognizing Israel's potential to be a leader in the growing international water-technology market, authorized a unique national program, called Israel NEWTech—Novel Efficient Water Technologies, to advance the sector internationally.[255] The government has allocated more than US$50 million over the next three years to advance the sector and increase exports. By 2010, Israel intends to double its exports in the water-technology field.[256]

Solar and Other Forms of Alternative Energy

Beyond water technologies, another environment-related field in which Israel is developing a strong track record is alternative energy, particularly solar energy. In the field of solar energy, Israeli R&D has already produced some innovative technologies, both in academic and industry research units. For example, diverse research projects are underway at Ben Gurion University's National Solar Energy Center to improve parabolic troughs and a parabolic dish.[257] In the late 1980s, one Israeli company developed such troughs, which generated electricity from solar energy for entire towns in Southern California until the decreased price of oil rendered the

[252] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech. The European Commission accepted Israel as a full partner in the European R&D program in 1993, after Israel signed the Oslo Accords.
[253] Israel Institute of Technology, Stephen and Nancy Grand Water Research Institute, "Introduction," http://gwri.technion.ac.il/.
[254] IVC–Israel Venture Capital Research Center, "Kinarot Incubator Privatized, Refocused on Hydro Tech," January 31, 2006, http://www.ivc-online.com/ivcWeeklyItem.asp?articleID=4023.
[255] Israel, Ministry of Industry, Trade, and Labor, Israel's Water Technologies, "Israel NEWTech: Israel's National Program for Promoting the Country's Water Industry," http://www.israelnewtech.gov.il/_Uploads/dbsAttachedFiles/newtech.pdf.
[256] Israel, Ministry of Industry, Trade, and Labor, Israel NEWTech.
[257] David Faiman, "Solar Energy in Israel," American-Israeli Cooperative Enterprise Web site, http://www.jewishvirtuallibrary.org/jsource/Environment/Solar.html (accessed March 9, 2008).

system uneconomical. At the Weizmann Institute, researchers are developing a solar furnace and central receiver tower in collaboration with industry.[258]

Currently, the Israeli company Solel, Ltd., is a major world leader in solar thermal power, solar energy plants, and solar collectors. The company was founded in 1992 with assets and employees from Luz Industries, the builder of three of the world's largest solar plants in California, which account for 90 percent of the world's solar thermal power production.[259] Solel now sets global standards for utility solar plants and high-temperature parabolic troughs. Israel is also a leader in photovoltaics, and is active in developing innovative methods for producing silicon solar cells, either from high-efficiency, single-crystal cells or from amorphous silicon thin layers. New thin-film materials are also being investigated for potential photovoltaic use. Israel itself provides a significant market for its solar technologies, whether thermal or photovoltaic. More than 70 percent of Israeli homes have rooftop solar collectors, which generate some 6 percent of the country's energy needs.[260]

Beyond solar energy, Israeli cleantech companies are active across the rest of the renewable energy spectrum. For example, the Israeli company Ormat is a world leader in energy converters that use locally available heat sources, including geothermal energy (steam and hot water), industrial waste heat, biomass, biogas, and low-grade fuels. Ormat currently provides the platform worldwide for dozens of geothermal power plants ranging from 200 kilowatts to 130 megawatts.[261]

A final environment-related subsector in which Israel is active—besides alternative energy and water treatment—is waste and pollution control. Israeli firms have developed technologies for various kinds of waste treatment, including compact sewerage systems, and methods for the treatment of medical and biological waste, toxic waste, and municipal sludge and solid waste. Enterprises have also developed technologies for toxin monitors for air and water and the prevention of industrial air pollution.[262]

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[258] Faiman.
[259] Israel21c, "Israeli Solar Energy Innovator Sees Multiple Ways to Serve U.S. Consumers," June 30, 2002, http://www.israel21c.org/bin/en.jsp?enDisplay=view&enDispWhat=object&enZone=technology&enDispWho=Articles%5El138&enPage=BlankPage.
[260] Faiman.
[261] Faiman.
[262] European Community Research and Development Information Service (CORDIS), "Israel: R&D Activities in Israel."

Israel's cleantech industry, while as yet limited when compared to, for example, the ICT sector, is one of the fastest growing in the country and the focus of increasing support. According to a survey conducted by the Samuel Neaman Institute, about 10 percent of all of the technological incubator projects are in the area of energy and ecology.[263] Ever more incubators have begun to invest in clean-technology companies. Apart from the water-technology incubators, the main players are GreenTech (the "Green" division of Mofet B'Yehuda), Meytag, and Yozmot HaEmek. Genova, a Misgav Technology Center company, which produces electric power from biomass, was an Israeli company singled out for entry on the *Red Herring* Europe 100 award for promising start-ups in the alternative-energy category.[264] Moreover, clean-technology projects have increasingly begun to interest business groups. Recently, Israel's Altshuler Shacham Group, a clean-technology investment company, invested US$4 million in L.N. Innovative Technologies, a Haifa-based incubator. As a result of this investment, L.N. Innovative Technologies' name changed to Eco Cycle, suggesting the direction of future investments.[265]

Military Technologies

Although Israel is diversifying its investments and expanding its support to fields such as cleantech, which have evident growth prospects, the country continues to devote a major portion of its R&D budget to the defense sector. Israel's policy in the defense sector has long been to leverage defense R&D to maintain a technological edge in its own homegrown defense industry. In pursuing this policy, Israel has become a significant innovator in military technologies. Competing successfully with the world's largest defense concerns, Israel is a major supplier of arms on the world market, ranking fourth in 2006 among the world's arms exporters, after the United States, Russia, and France.[266] In fact, Israel's defense industries maintain an unusual

[263] D&A Hi-Tech Information Ltd., "Renewable and Alternative Energy Technologies in Israel," http://www.dainfo.com/HPage.aspx.
[264] IVC–Israel Venture Capital Research Center, "25 Investors Attend First Israeli Cleantech Companies Conference," May 28, 2006, http://www.ivc-online.com/ivcWeeklyItem.asp?articleID=4448.
[265] D&A Hi-Tech Information Ltd., "Renewable Energy in Israel," September 2006, 11, http://www.export.gov.il/Eng/_Uploads/4303Renewable.pdf.
[266] Neal Sandler, "In Tense Times, Israeli Arms Biz Booms," *Business Week*, May 17, 2007, http://www.businessweek.com/globalbiz/content/may2007/gb20070517_462283.htm.

balance between domestic sales and exports, with 80 percent going to exports.[267] In 2006 the value of Israel's defense exports came to more than US$4 billion, or roughly 10 percent of total global exports.[268] Military technologies in which Israel is at the cutting edge include unmanned vehicles of various scales, missile countermeasures and missile technology, and satellites. Israel is a leading developer in surveillance and communication satellites, anti–ballistic-missile defense systems, electronic warfare systems, electro-optical systems, air-to-air missiles, and weapons upgrades.

Israel faces a challenge in the future in maintaining its leadership in state-of-the-art arms development. This challenge stems partially from reductions in the money Israel appropriates for weapons R&D. Although expenditure for military R&D remains high, such spending has been cut since the end of the Cold War, and the proportion of R&D efforts devoted to the military has declined in relation to total R&D expenditures.[269] Falling military R&D expenditures have been one of the major problems encountered by the Israeli arms industry. The industry, like defense industries elsewhere, has suffered from the decline in global military spending in the 1990s and beyond. Israel's defense industry also faces unique challenges that stem largely from the country's intimate relationship with the United States in military matters. Although Israel benefits from U.S largesse in the military arena, including U.S. underwriting of Israeli R&D of weapons, Israel's defense industry pays a price for U.S. grants and aid.[270] Israel is the largest cumulative recipient of U.S. aid since World War II, and the largest annual recipient since 1976, receiving more than US$3 billion per year, or one-fifth of the total U.S. international aid budget.[271] Of this US$3 billion, more than US$2 billion consists of military grants, an amount that is slated to grow.[272] However, U.S. grants and aid have a downside.[273] U.S. aid carries the stipulation that Israel must buy about three-quarters of the weaponry for its armed forces from the U.S. arsenal, thereby depriving Israel's defense industry of much of its local market.

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[267] "A Banner Year for Israeli Exports," *Business Week*, March 7, 2005, http://www.businessweek.com/magazine/content/05_10/b3923097_mz015.htm.
[268] Sandler.
[269] Sandler.
[270] Jeremy M. Sharp, "U.S. Foreign Aid to Israel," *CRS Report to Congress*, RL33222, January 5, 2006, http://www.fas.org/sgp/crs/mideast/RL33222.pdf.
[271] Frida Berrigan and William D. Hartung, "U.S. Military Assistance and Arms Transfers to Israel: U.S. Aid, Companies Fuel Israeli Military," *Arms Trade Resource Center Reports*, World Policy Institute, July 20, 2006, http://www.worldpolicy.org/projects/arms/reports/israel.lebanon.FINAL2.pdf. See also Migdalovitz.
[272] Sharp.

Moreover, when Israeli industry attempts to export arms to compensate for the loss of domestic sales, it faces restrictions. The United States, as Israel's main arms supplier, claims the right to veto Israel's arms exports to certain countries, e.g., China, India, and Russia.[274] As a result of such hindrances on both domestic and foreign sales, the profitability of the Israeli defense industry is inconsistent, necessitating cost-cutting efforts that all-too-often target the funding for R&D of new military technology.[275]

Despite facing such challenges, the Israeli defense industry continues to loom large in the Israeli economy and to generate, as it did most notably in the early 1990s, spillovers into civilian industry. The defense industry comprises some 150 defense firms, which employ about 50,000 people, most of whom have experience with the Israeli Defense Forces. The three largest entities are the partly government-owned Israel Aerospace Industries (IAI) (Israel Aircraft Industries until November 2006), Israel Military Industries (IMI), and Rafael Armament Development Authority, all of which produce a wide range of conventional arms and advanced defense electronics.[276]

Of the three major firms, IAI is the largest. Launched by the government in 1951, the company metamorphosed from a small arms producer into a producer of more costly aircraft and advanced weapons after the 1967 Six-Day War. At that time, Israel's foreign suppliers, principally France, imposed an arms embargo on Israel. In response, IAI, with U.S. help, began developing its own aircraft, including the Kfir—a substitute for France's Mirage—as well as the Nesher and Arava airplanes. At the same time, IAI gradually undertook joint ventures with Lockheed–Martin and Boeing and gained the capability to develop an all-Israeli combat aircraft, the Lavi. Although the Lavi jet fighter project was cancelled in 1987 because it was too expensive, the process of producing the prototype enhanced the company's expertise in electronics, avionics, and weapons systems. This expertise enabled the company to diversify into sophisticated weaponry and, with U.S. funding, to expand. By 2000, company sales reached

[273] Anne Rosenzweig, "Weapons of Self-Destruction: The Challenges and Strategies of Israel's Defense Industry," *Yale Israel Journal*, no. 2 (Winter 2004), http://www.yaleisraeljournal.com/wintr2004/weapons.pdf.
[274] Sharp. As Sharp reports, over the years, bilateral U.S.-Israeli conflicts have regularly arisen over Israel's plans to share or sell sensitive military technologies and security equipment to various countries. Recent conflicts in U.S.-Israeli relations involve Israel's military sales to China, inadequate Israeli protection of U.S. intellectual property, and espionage-related cases.
[275] Sharon Sadeh, "Israel's Beleaguered Defense Industry," *Middle East News Online*, March 13, 2001 (via Proquest).
[276] See Raphael Advanced Defense Systems Ltd. Web site, http://www.rafael.co.il.

US$2.18 billion, of which exports accounted for US$1.7 billion.[277] IAI has been the central player in the majority of Israel's most ambitious military projects, including unmanned air vehicles (UAVs or pilotless aircraft), such as the Hunter, the world's first operational antimissile missile system, the Arrow, and the Ofek and Amos series of satellites.[278] The company is also internationally prominent in the repair of aircraft and helicopters, and in upgrading aircraft with state-of-the-art avionics. One such example is the Phantom 2000 project, a thorough modernization of the F–4 aircraft that Israel acquired from the United States in the early 1970s.[279] IAI also designs, develops, and manufacturers naval and ground systems, electronic warfare and radar equipment, and missiles.

Israel Military Industries (IMI), founded in 1933 as a secret small-arms plant, remains a maker of mostly small arms, including the classic Uzi submachine gun, the Tavor assault rifle, grenades, and mortar and artillery ammunition.[280] The company also develops aircraft and rocket systems, armored vehicles, such as the Merkava tank, and integrated security systems and manufactures some 350 other products.[281] The Merkava (*chariot* in Hebrew) tank, considered one of the world's safest and most effective battle tanks, became operational in 1979, with successive models—those currently in use—appearing in 1983 and 1990. A Mark IV model is currently in production by the company.[282] The company has 4,000 employees and distributors in a number of countries besides Israel, including Belgium, Greece, Norway, the Philippines, and the United States. Some 60 percent of its revenues, worth approximately US$550 million, come from exports.[283]

The third major defense firm, the partially government-owned Rafael Arms Development Authority, is the national authority for the development of weapons and military technology. The company is known as the developer of the Python and Popeye "smart" airborne missiles, both of which have co-production agreements with major U.S. aerospace companies. The company's

[277] "Military Industry," GlobalSecurity.org Web site, http://www.globalsecurity.org/military/world/israel/industry.htm (accessed March 17, 2008).
[278] Hanan Sher, "The Defense Industry," *Facets of the Israeli Economy*, http://bombay.mfa.gov.il/mfm/Data/8728.pdf.
[279] "Military Industry."
[280] Israel Military Industries Web site, http://www.imi.co.il.
[281] Sher.
[282] "Merkava Mk 4," www.Israeli-Weapons.com, http://www.israeli-weapons.com/weapons/vehicles/tanks/merkava/MerkavaMk4.html.
[283] American-Israeli Cooperative Enterprise, "The Israeli Defense Industry," 2002, http://www.jewishvirtuallibrary.org/jsource/Economy/eco1.html.

products also include such varied categories as passive armor for fighting vehicles; naval decoys; observation balloon systems; acoustic torpedo countermeasures; ceramic armor; air-breathing propulsion; air-to-air, air-to-surface, and surface-to-surface missiles; and the Litening Targeting Pods used to fire precision weapons from jets.[284]

In addition to the three large firms that comprise Israel's defense industry, Israel has a number of medium-sized, privately owned companies, namely, Elbit Systems and the Tadiran Group, which focus mainly on defense electronics.[285] Numerous smaller private firms also exist, producing a narrower range of products. The mid-sized private firms, and some of the smaller companies, are shown in table 11.

Table 11. Israeli Defense Industry: Private Sector

Company and Subsidiaries	Size	Activities
BVR Technologies	Small, Private	Makes airborne collision-avoidance security systems, trainers for pilots and for the use of "smart" weapons, and a variety of simulators for combat training and pilot debriefing.
Cyclone Aviation	Small, Private	Upgrades helicopters and makes aircraft components.
Elbit Systems, based in Haifa. In 2000 merged with private-sector defense concern Electro-Optics Industries Ltd. (El-Op)	Medium, Private	International defense electronics company. Operates in areas of aerospace; land and naval systems; command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR); advanced electro-optics and space technologies; electronic-warfare suites; airborne warning systems; and data links and military communications systems and equipment, including helmet-mounted systems. The Group also focuses on aircraft and armored vehicle upgrades, and on developing new technologies for defense and homeland security applications.
Elul Group	Small, Private	Develops and coordinates defense business for Israeli firms abroad and for foreign firms in Israel.
Magal Security Systems	Small, Private	Makes sensors for security perimeter fences and explosive-detection devices for airports and other public facilities.
RSL Electronics	Small, Private	Provides airborne electronics systems for airplanes and helicopters and muzzle-velocity radar for field artillery.

[284] Sher.
[285] Elbit Systems Web site, http://www.elbit.co.il.

Table 11. Israeli Defense Industry: Private Sector

Company and Subsidiaries	Size	Activities
Soltam	Small, Private	Makes mortars and heavy artillery pieces, as well as Israel's most popular line of stainless steel kitchen equipment.
Tadiran Group	Medium, Private	Subsidiaries specialize in defense electronics. The group's Elisra Electronics offers a range of intelligence and electronic warfare systems for the military, including radar warning systems, comprehensive self-protection systems, ESM and ELINT systems, specialized communication links complemented by lightweight components, and pilot rescue electronic equipment. In addition, the company offers advanced technology with its Theater Missile Defense (TMD) systems and the Israeli Test Bed (ITB), which simulates theater ballistic missile attacks against multiple targets, and the defense action taken by the weapon systems controlled by Battle Management, Command and Control (BM/C2) centers. This technology is utilized in Citron Tree, the BM/C3I center of the Arrow Weapon System.
Urdan Industries, and its Associated Steel Foundries	Small, Private	Makes components for the Merkava tank.
Source: Based on Hanan Sher, "The Defense Industry," *Facets of the Israeli Economy*, http://bombay.mfa.gov.il/mfm/Data/8728.pdf.		

Because even the larger Israeli firms are relatively small compared to the world's weapons industry giants, Israeli companies have tended to specialize in niche markets, or to combine forces through local or international mergers and joint development and marketing efforts.[286] These business strategies have contributed to Israel's prominence as an arms and military services exporter. Israel's top customers for arms are India and the United States. After decades of U.S. military aid and defense cooperation, the U.S. military, in the words of an Associated Press release, " is permeated by technology developed in Israel," including such weaponry and arms technology as the U.S. Army's Hunter drones, the targeting systems on the U.S. Marines' Harrier jets, and the fuel tanks on its F–15 fighters.[287] In 2004 India became the

[286] "Israel Military Guide: Military Industry," GlobalSecurity.org Web site, n.d., http://www.globalsecurity.org/military/world/israel/index.html.
[287] "U.S. Military Employs Israeli Technology in Iraq War," *USA Today*, March 24, 2003, http://www.usatoday.com/tech/world/iraq/2003-03-24-israel-tech_x.htm.

Israeli defense industry's top customer.[288] Also important in Israel's client base are Brazil, Canada, Germany, and Turkey. China has been a major client, although Israel has backed off on some sales activity after protests from the United States.[289] Israel reportedly remains China's second major arms supplier, after Russia.[290]

A decade-by-decade review of the Israeli defense industry's products reveals the R&D-based growth in sophistication and diversity that has sustained both local and international sales (see table 12). The categories of innovative products resulting from Israel's commitment to high levels of R&D include unmanned aerial vehicles and other weapons, missile countermeasures, and satellites, as discussed below.

Table 12. Timeline of Israel's Weapons and Military Technologies

Decade	Product
1940s	Hand grenades, submachine guns, mortars, armored cars.
1950s	Uzi submachine gun, small arms, ammunition.
1960s	Jericho intermediate-range ballistic missiles; first-generation non-conventional capabilities; Fouga Magister jet trainer (licensed production); Gabriel antiship missile.
1970s	Unmanned aerial vehicles; laser range-finders and designators; Galil assault rifle; Reshef missile boat family; Kfir fighter; Merkava tank; Barak surface-to-air missile; Popeye air-to-ground missile.
1980s	Electronic-warfare suites, ELINT and COMINT systems; thermal imaging and electro-optical systems; Ofek reconnaissance satellite; Jericho ballistic missile Mark 2; Harpy attack UAV; Lavi fighter (cancelled); secured communication systems; deciphers and encoders; Python–4 all-aspect air-to-air missile; directed-energy weapons; advanced armor techniques and antiarmor weapons; energy weapons.
1990s	Attack multipurpose UAVs; complex composite structures; cyber-warfare; Arrow anti–ballistic missile; simulators; electronic warfare systems; communication systems; remote sensing; antitank guided missiles; cruise missiles; upgrade programs; Merkava tank Mark 4.

Source: Based on Sharon Sadeh, "Israel's Beleaguered Defense Industry," *Middle East News Online*, March 13, 2001 (accessed February 27, 2008, via Proquest).

[288] "A Banner Year for Israeli Exports," *Business Week.*

[289] Uzi Eilam, "Defense Export Control in 2007: State of Affairs," *Strategic Assessment* 9, no. 4 (March 2007) (Jaffee Center for Strategic Studies, Tel Aviv University), http://www.tau.ac.il/jcss/sa/9_4_09.html. The United States has taken issue with some sales as potentially harmful to the security of U.S. forces in Asia. In 2000 the United States persuaded Israel to cancel the sale to China of the Phalcon, an advanced, airborne early-warning system. In 2005 the U.S. Department of Defense was angered by Israel's agreement to upgrade Harpy Killer unmanned aerial vehicles (UAVs) that it sold to China in 1999. China tested the weapon over the Taiwan Strait in 2004. The Department suspended technological cooperation on some projects for a time. In October 2005, Israel reportedly froze a deal to upgrade 22 Venezuelan Air Force F–16 fighter jets with some U.S. parts and technology. The Israeli government had requested but not received U.S. permission to proceed.

UAVs and Other Unmanned Weapons

Israel has long been prominent in the design and production of unmanned aerial vehicles. It has been developing UAVs since the mid-1970s and is the first nation generally acknowledged to have made UAVs a standard military weapon.[291] Israel is also now considered, along with the United States, to be the main innovator in the UAV field, notwithstanding the involvement in UAV development of at least a dozen other countries—Australia, Belgium, China, France, Germany, Italy, Japan, the Netherlands, South Korea, and the United Kingdom.[292]

Israel currently pursues a broad UAV effort, having some 20 programs, including the Searcher II (reconnaissance), the Hermes 180 tactical UAV, the delta-winged Cutlass (combat uninhabited target locate and strike system) "search and destroy" vehicle, and the Micro–V mini UAV.[293] Israel also is one of the major producers of research into ways of silencing the telltale engine noise of most UAVs, and a prime international exporter of UAVs.[294]

Small and Medium-Sized UAVs

Israeli companies are leaders in the development of mini and micro UAVs and excel in the production of UAV sensor payloads and guidance systems for UAVs of various types. Some eight manufacturers design and build UAVs in Israel, most notably, Elbit Systems and IAI Malat, the two leading Israeli manufacturers of mini reconnaissance and surveillance UAVs. Israel produces medium-sized, as well as small UAVs, for its own use and for sales abroad to countries such as Australia, Singapore, and the United Kingdom. [295]

Israel, along with Italy, Japan, Singapore, South Korea, the United Kingdom, and the United States, has designed and built a type of small UAV designed to hover, the vertical takeoff-and-landing UAV **(**VTOL UAV). Israel's VTOLs, like those of other countries, are about two meters in diameter and resemble either small helicopters or ducted fans. Israel is also a leader in swarming research, developing technology that would allow UAVs to control

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[290] Eilam.
[291] J.R. Wilson, "UAVS: A Worldwide Roundup," *AIAA—Aerospace America Online*, http://www.aiaa.org/aerospace/Article.cfm?issuetocid=365 (accessed March 20, 2008).
[292] Wilson, "UAVS."
[293] Wilson, "UAVS."
[294] Wilson, "UAVS."
[295] Patrick M. Miller, *Mini, Micro, and Swarming Unmanned Aerial Vehicles: A Baseline Study* (Washington, DC: Federal Research Division, Library of Congress, November 2006), 2.

themselves and operate in a swarm, like a flock of birds in flight. Scientists at the Technion, along with others in Australia, Germany, the Netherlands, the United Kingdom, the United States and, to a degree, China and South Korea, are tackling the main technical challenges for swarming UAV research, namely, collision avoidance, path planning, and swarm search patterns.[296] In August 2007, the Technion team announced progress against these challenges and has now applied for a patent for their technology.[297]

Israel's Large UAV: Surveillance and Weapons Capabilities

In addition to its development of small- and mid-sized UAVs, Israel is developing a larger and longer-range type of UAV—a medium-altitude long-endurance (MALE) UAV, the latest Israeli version of which is the Heron TP or "Eitan." The Heron TP is a giant drone that weighs four tons—four times the weight of the largest UAV hitherto in the Israeli air force—and attains 14 meters in length, with a wingspan of 26 meters.[298]

Resembling a fighter jet, the multipurpose Heron TP, an enhanced version of the Heron (Mahatz), has been developed by Israel Aerospace Industries/Malat for the Israeli air force to carry out strategic reconnaissance and, possibly, attack missions. Heron TP made its maiden flight on July 15, 2006, in Israel. As of June 2007, IAI considered the Heron TP ready for serial production. Like its predecessor, the Heron TP is fully autonomous throughout the mission, including in the automatic takeoff and landing phases. The turbo-prop vehicle is designed to fly at high altitude—40,000 feet—on missions of up to several days, to carry multiple payloads, and to perform missions, including communications intelligence (COMINT), signals intelligence (SIGINT), imagery intelligence (IMINT), and communications relay. The aircraft is equipped with multiple datalinks, supporting line-of-sight (LOS) and beyond line-of-sight (BLOS) links via satellite communications.[299]

Apart from long-range, long-endurance intelligence, surveillance, and target-acquisition reconnaissance (ISTAR) missions, Heron TP is designed to execute a large variety of operational

[296] Miller, 5.
[297] "Invention: UAV Swarms," *New Scientist*, August 29, 2007, http://www.newscientist.com/blog/invention/2007_08_01_archive.html.
[298] "Eagle MALE System, Medium Altitude Long Endurance UAV, EADS/IAI," *Defense Update*, no. 2, 2005, http://www.defense-update.com.
[299] "Heron TP (Eitan) Medium Altitude Long Endurance UAV," *Defense Update*, http://www.defense-update.com/products/e/eitan-UAV.htm (accessed March 20, 2008).

missions, including aerial refueling and even strategic missile defense.[300] In fact, the first application considered for a MALE UAV in the mid-1990s was as an alternative to the Arrow ballistic-missile defense system, also developed by IAI. One of the missions now envisioned would be to locate and destroy mobile ballistic-missile launchers.

A derivative of the Heron, the Eagle, can also carry several types of sensors, including maritime-patrol radar (MPR), different types of synthetic aperture radar/moving target indication (SAR/MTI), electro-optics/infrared (EO/IR) payloads, SIGINT, COMINT, laser designator, communications relays, etc.[301] The Eagle was chosen by the French air force to provide strategic and theater reconnaissance, intelligence collection, and communications support.[302] It is also expected to operate in the maritime surveillance and antisurface warfare role. The Eagle is designed to operate on missions of more than 40 hours at an altitude of 30,000 feet and can carry multiple payloads up to a total weight of 250 kilograms.

Israeli UAV companies have aggressively pursued the international UAV market, with some companies partnering with others in order to promote sales. Listed below are some recent examples of collaborations and significant sales between Israeli UAV producers and partners or customers in Australia, Canada, Poland, Singapore, and Turkey:

- In May 2005, IAI announced a Turkish procurement contract worth US$150 million, under which the Turkish TUSAS Aerospace Industry subcontracted with a company owned jointly by IAI and Elbit Systems to supply Heron UAVs and Elbit Systems ground systems to the Turkish MOD. Under another contract worth US$50 million, the Israel MOD would supply Heron UAVs and multiyear support. According to IAI, the Heron UAVs will replace the Searcher I and II currently in service.[303]
- In December 2005, Australia purchased six Israeli Elbit Skylark IV systems (for a total of 18 UAVs) for operations in Iraq.[304]
- In May 2006, Israel's IAI partnered with Boeing Australia to outbid Australia's AAI/BAE Systems for sales of coast-monitoring UAVs to Australia's military. To help their bid, IAI and Boeing Australia proposed to "support the establishment of a UAV center of excellence in Queensland."[305]

[300] "Heron TP (Eitan) Medium Altitude Long Endurance UAV," *Defense Update*.
[301] "Heron MALE System: Medium Altitude Long Endurance UAV," *Defense Update*, http://www.defense-update.com/products/h/Heron-UAV.htm (accessed March 20, 2008).
[302] "Israel Sells Heron UAVs to India, Australia," *Defense Industry Daily*, November 11, 2005, http://www.strategypage.com/militaryforums/512-20022.aspx.
[303] "Heron MALE System," *Defense Update.*
[304] Ian Kemp, "Controlling Drones at War," *Armada International* (Zurich), February/March 2006, 26.
[305] Tim Mahon, "Taking Off; Australian Industry Grows with UAV Needs," *C4ISR Journal*, June 1, 2006, 28 (accessed through Lexis-Nexis).

- In June 2006, Elbit sold Skylark mini UAVs to the Canadian Army.[306]
- In September 2006, Elbit Systems signed a production and export agreement with Poland's Bumar Capital Group. Bumar will manufacture optical and measuring equipment for some Elbit UAVs and market Elbit UAVs to the Polish military.[307]
- Singapore's UAV industry currently is working with Israel to develop the Firefly UAV.[308] In the past, Singapore sold the Israeli Blue Horizon UAV to the Philippines.[309]

Israel's New Stealth Unmanned Boat: "Death Shark"

Aerial drones are not the only type of unmanned weapons in which Israel has demonstrated leadership. In 2005, in the most recent unveiling of robotic weapons, the Israeli navy deployed a speedboat drone capable of reaching enemy targets hundreds of miles from Israeli shores.[310] Analysts believe that the so-called "Death Shark," or what the IDF calls the "Protector," has existed since about 2004, with hundreds now deployed throughout the waters of the Middle East and Mediterranean. The primary mission of the "Death Shark" is to defend Israeli waters and the coastline from terrorist attack. The IDF plans to deploy it for dangerous tasks, such as approaching suspicious craft at sea. The "Death Shark" will be used to protect Israel's merchant marine fleet and civilian vessels in the Middle East and throughout the world. The unmanned speedboat—a nine-meter-long inflatable vessel of "all-Israel" assembly—is equipped with a remote-controlled machine gun capable of being operated with laser accuracy up to a range of 50 kilometers, reportedly the first of its kind in the world. The machine gun is a mini-Typhoon type, developed by Israel's Rafael. The Typhoon system allows the gun to stay on target as the unmanned surface vehicle (USV) plies the waves. According to defense analysts who have studied photos of the drone, the Rafael Industries weapon is equipped with high-definition imaging equipment capable of seeing a license plate number from a distance of 10

[306] "Israel: Roundup of Defense Industries' Deals, Innovations 25 Jun–6 Jul 06," July 8, 2006, https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_1019_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/6220970?action=advancedSearch&highlightQuery=eJzTcPcNMDIwMDMwN7AwNzEwMDDVBAAp3gP9&fileSize=42826, accessed through Open Resource Center Document GMP20060708740005.
[307] "Helicopter Suppliers Court Poland's Defence Industry," *Jane's Online*, September 14, 2006, http://www.janes.com.
[308] "Singapore Sets the Pace," *Global Defence Review*, 2001, http://www.global-defence.com/2001/RSpart3b.html.
[309] Manjeet Singh Pardesi, "UAVs/UCAVs-Missions, Challenges, and Strategic Implications for Small and Medium Powers," Institute of Defence and Strategic Studies, Singapore, May 2004, http://www.idss.edu.sg/publications/WorkingPapers/WP66.PDF.
[310] "Israeli Navy's New Stealth Unmanned Boat," *African Crisis*, December 13, 2005, http://www.africancrisis.org/ZZZ/ZZZ_News_006841.asp.

miles.[311] The drone could be especially useful when weather conditions "soften" satellite surveillance. Some believe that the drone is capable of turning itself into a mini submarine.[312]

Missile Countermeasures: Interceptors and Lasers

With funding from the United States, Israel is continuing to focus R&D resources on missile countermeasures of various kinds, most notably, missile interceptors for ballistic missiles.

Israel aims to have four levels of ballistic-missile defense, each level capable of intercepting incoming missiles with different operational ranges. When complete, this multilayered defense system will consist of Arrow missiles for longer-range incoming ballistic missiles and several other types for shorter-range threats. The top levels, levels three and four, will consist of Arrow and Arrow 2 systems, respectively. For the range below the two Arrow types, a missile called David's Sling, a co-production of Israel's Raphael and the U.S. military contractor Raytheon, is intended to cope with short-range missiles in the region. The system is expected to be operational within four years. Israel is also pushing ahead with Iron Dome, the lowest level of its four-tiered system for countering ballistic threats.[313] Iron Dome, approved at the beginning of 2007, is a three-year program to deploy very-short-range ballistic-missile interceptors that could intercept incoming missiles with a range of 25 miles or less.

Arrow Missile: A Homegrown Israeli Theater Ballistic-Missile Interceptor System

The Arrow missile system has been one of Israel's most ambitious projects in defense R&D. Called a Theater Defense System, the Arrow missile system is designed to destroy incoming short- to medium-range ballistic missiles in their terminal phase (the phase in which they have passed through space and are re-entering the atmosphere) at altitudes between 10 and 40 kilometers.[314] The Arrow system, a central component of the multitiered and diverse Israeli response to the threat of ballistic missiles, has been developed in close cooperation with the

[311] Joel Leyden, "Israel Defense Forces Navy Unleashes Death Shark Against Terrorism," http://www.israelnews agency.com/navyterrorismisraelidfweapons481020.html (accessed March 21, 2008).
[312] Leyden.
[313] Barack Ravid, "Officials: Gov't Mulling Resumption of Skyguard Missile Defense Project," *Ha'aretz* on-line edition, August 2, 2007, http://www.haaretz.com/hasen/spages/889167.html.
[314] United States, Department of Defense, Missile Defense Agency (MDA), "Terminal Phase Defense," n.d., http://www.acq.osd.mil/mda/mdalink/html/terminal.html (accessed January 15, 2008).

United States, which also financed the lion's share of its development.[315] The project's price tag is expected to exceed US$2 billion by 2010, with direct U.S. funding accounting for about half.[316] The U.S. funding for the Arrow is authorized and appropriated through the annual U.S. defense budget.

Israel began to develop the U.S.-funded Arrow interceptor in the 1980s as part of the Reagan Administration's now-defunct Strategic Defense Initiative (SDI) or "Star Wars." The Arrow project was accelerated by the failure of U.S.-supplied Patriot missiles to combat Iraqi Scud missiles fired into Israel during the 1991 Gulf War.[317] By the mid-1990s, an upgraded, two-stage Arrow 2 was developed.[318] The first operational batteries of the Arrow system were deployed in Haifa in 2000 and in Tel Aviv in 2002. A decision on deployment of a third battery has not been finalized, but it is under discussion for service entry in 2012.[319] The United States continues to assist Israel with improvements and upgrades to the Arrow system, including anti-ballistic-missile-system interception tests that were completed under the Arrow System Improvement Program (ASIP) at Point Mugu, California, in July and August 2004.[320] The program tested the complete Arrow system: the Green Pine radar that acquires the target, the Yellow Citron control system that calculates intercept data, and the actual missile that is launched to strike the target.[321] In the first test, the missile successfully intercepted the target, while in the second, the intercept failed.[322] Testing resumed in December 2005, leading to various results, including, in February 2007, the successful inception of a simulated ballistic-

[315] Barbara Opall Rome, "Test Demonstrates Israel's Growing Missile Defense Capabilities," *Space News*, December 12, 2005, http://www.space.com/spacenews/archive05/Arrow_121205.html.
[316] Bradley Burston, "Israel's Missile Killer Declared Operational," November 1999, http://www.space.com/news/israel_missile_991101_wg.html.
[317] Burston, "Israel's Missile Killer Declared Operational."
[318] United States, Department of State, "U.S. Pursues Cooperative Approach to a Limited Missile Defense" (remarks by Stephen G. Rademaker, Assistant Secretary of State for Arms Control Remarks, to the American Foreign Policy Council's 2004 Conference on "Missile Defenses and American Security"), U.S. State Department Web site, December 17, 2004, http://usinfo.state.gov/eap/Archive/2004/Dec/20-761571.html?chanlid=eap.
[319] "Arrow 2 Theatre Ballistic Missile Defence System, Israel," Army–Technology.Com, n.d., http://www.army-technology.com/projects/arrow2/ (accessed February, 28, 2008).
[320] "Arrow Anti-Ballistic Missile System Completes Successful Interception at Point Mugu in a Joint U.S.-Israel Test Program," Israel Aircraft Industries Web site, July 29, 2004, http://www.iai.co.il/site/en/iai.asp?pi=23048&doc_id=32551.
[321] "Arrow Anti-Ballistic Missile Systems' Second Test at Point Mugu, U.S.," Israel Aircraft Industries Web site, August 29, 2004, http://www.iai.co.il/site/en/iai.asp?pi=23048&doc_id=32850.
[322] "Arrow Test Shows Success Against Iran Missile Threat: December 5 Trial Result Is A Successfully Destroyed Shihab 3-Type Target," *JINSA (Jewish Institute for National Security Affairs) Online* January 19, 2006, http://www.jinsa.org/articles/print.html/documentid/3290.

missile target at high altitude.[323] In 2007 the United States agreed to extend funding for the ASIP for an additional five years, to 2013. During that period, Israel will be developing a third version of the Arrow missile to provide defense against intermediate-range ballistic missiles. The Arrow 3 will be an exo-atmospheric missile, capable of greater altitudes and longer distances than its predecessors.[324] IAI has announced plans to test the Arrow 3 for the first time in late 2008. The director of Israel's Missile Defense Organization estimated that it would take at least five years and "several hundred million dollars" for the first Arrow 3 to become operational.[325]

As Israel continues to invest effort and money in developing versions of the Arrow antimissile system, it is also developing, with U.S. help, David's Sling and Iron Dome, the missile interceptors that are to be used at the lower levels of its anti-ballistic-missile defense system.[326] By mid-2007, U.S. allocations for the development of the David's Sling missile added up to at least US$200 billion.[327] Israel also participates in other antimissile projects, for example, jointly with India, the development of the Barack–8 surface-to-air missile.[328] Under development since 2006, this vertically launched air defense system is expected to take four years to develop and to cost more than US$300 million. Israel has less well-developed capabilities for countering low-flying cruise missiles.[329]

Short-Range Missile Countermeasures: Lasers and Directed Infrared

Besides focusing R&D resources on launched missile interceptors, Israel has until recently participated in research on other types of missile countermeasures that use directed energy, or lasers, for relatively short-range defense. For about 10 years—up to early 2006—Israel was a partner with the United States in the development of the laser antimissile system "Tactical High Energy Laser" (THEL), a high-energy chemical laser designed to detonate

[323] "Israel Successfully Tests Arrow Theater Missile Defense," *Defense Industry Daily*, December 5, 2005, http://www.defenseindustrydaily.com/israel-successfully-tests-arrow-theater-missile-defense-01571/.
[324] "Missile Monitor: Two Test Announcements," February 5, 2008, http://missilemonitor.blogspot.com/2008/02/two-test-announcements.html.
[325] "Missile Monitor: Two Test Announcements."
[326] Mark Williams, "The Missiles of August: The Lebanon War and the Democratization of Missile Technology," *Technology Review*, August 16, 2006, http://www.technologyreview.com/Biztech/17314/.
[327] "David's Sling," *Missile Monitor*, October 14, 2007, http://missilemonitor.blogspot.com/2007/10/davids-sling.html.
[328] Nuclear Threat Initiative (NTI), "Country Overviews, Israel: Missile Chronology," April 2008, http://www.nti.org/e_research/profiles/Israel/Missile/3571_6330.html.
[329] "X-55 Long Range Cruise Missile," GlobalSecurity.org, n.d., http://www.globalsecurity.org/wmd/world/iran/x-55.htm.

missiles in mid-flight.[330] Although Israel dropped out of this U.S.–Israeli project in early 2006, because of its expense and the prototype's impractically large size, debate in Israel's defense establishment is ongoing about the desirability of participating in the development of new versions of directed-energy systems. Of particular interest is a revived, smaller-scale version of THEL called Skyguard, a system that would be built by Northrup Grumman.[331] The Skyguard version of THEL is designed mainly to protect aircraft from portable antiaircraft missiles fired near airports.[332]

Israel has produced breakthroughs in chemical lasers that could have both military and commercial applications. Researchers in the Department of Physics at Ben Gurion University (BGU), for example, have developed an oxygen-iodine chemical laser with a record efficiency level.[333] In 2003 the BGU Chemical Oxygen-Iodine Laser was selected by the American Institute of Aeronautics and Astronautics as one of the year's significant S&T breakthroughs with implications for the air and space field.[334] The chemical laser developed at BGU opens up less expensive possibilities for the future use of chemical laser technology. While laser development is moving ahead in a number of countries, including the United States, Russia, China, Japan, and Germany, most of the lasers being developed are extremely large in size.[335] Israel's smaller chemical laser produces more laser power with smaller amounts of cheaper chemical reagents and, thus, has promise for numerous industrial and defense applications. Possible industrial applications include an alternative form of drilling for oil, large-scale welding and cutting, and clearing debris after an earthquake. The United States is interested in the lasers' potential military application as an antimissile weapon, in the form of an airborne laser (ABL) that would be mounted on aircraft. An ABL-equipped aircraft could patrol territory from 40,000 feet, detect when a missile is being put into the vulnerable "boost phase" before launch, and aim

[330] Union of Concerned Scientists, "Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defense System: Executive Summary," April 11, 2000, http://ucsusa.org/global_security/missile_defense/countermeasures.html.
[331] Nuclear Threat Initiative (NTI), "Country Overviews, Israel: Missile Chronology," April 2008. See also "Secret Meeting," *Defense Daily International* 7, no. 28 (July 14, 2006).
[332] "Skyguard," *Defense Update*, 2006, http://www.defense-update.com/products/s/skyguard-laser.htm.
[333] Israel21c, "Israeli-Developed Chemical Laser Lauded as Significant Breakthrough for 2003," December 28, 2003, http://www.israel21c.org/bin/en.jsp?enScript=PrintVersion.jsp&enDispWho=Articles^l586.
[334] Israel21c, "Israeli-Developed Chemical Laser Lauded as Significant Breakthrough for 2003."
[335] "Israel Develops Chemical Super-Laser," *Israel National News*, December 30, 2003, http://www.israelnationalnews.com/News/News.aspx/55388.

the laser to destroy it.[336] Israel is also interested in "boost-phase launcher intercept" (BPLI) and is thought to be working on a launcher attack project to develop an unmanned aircraft that would find and destroy mobile ballistic missile launchers.[337]

In addition to its continuing interest in chemical lasers, Israel has active involvement in a joint Israeli–Italian project to develop a laser-based direct infrared countermeasures (DIRCM) system.[338] Such DIRCM systems are intended primarily to protect helicopters and larger fixed-wing aircraft during their takeoff and landing phases against low-altitude attack by shoulder-fired man-portable air defense (MANPAD) heat-seeking missile systems.[339] In 2007 El–Op, the electro-optics subsidiary of Israel's Elbit Systems, and Italy's Elettronica established a partnership to create defense solutions based on El–Op's multispectral infrared countermeasure (MUSIC) system. The system, an advanced laser-based DIRCM protection system, integrates fiber laser technology with a small turret and can operate with most types of missile approach warning systems (MAWS) and defensive aids subsystems (DASS). The Israeli–Italian company collaboration will offer systems solutions for the protection of aircraft worldwide, with early deliveries for the laser-based systems expected by the end of 2008.[340]

Israeli International Relations in Missile Countermeasures

Israel's R&D-based innovations in defensive missile systems, like its innovations in UAVs, have attracted the interest of international buyers and partners. For example, in July 2004 IAI, the prime contractor for the Arrow system, signed a Memorandum of Understanding with Europe's leading guided missile company, MBDA.[341] Under the agreement, the two companies will "evaluate mutually reinforcing technologies and experience in order to support future ballistic missile interceptor system concepts."[342] In March 2005, it was also reported that IAI plans, at an unspecified time in the future, to sell Arrow 2 technology to India, the largest

[336] Israel21c, "Israeli-Developed Chemical Laser Lauded as Significant Breakthrough for 2003."
[337] Clyde R. Mark, "Israel: U.S. Foreign Assistance," *CRS Issue Brief for Congress*, IB85066, updated April 26, 2005, http://www.fas.org/sgp/crs/mideast/IB85066.pdf.
[338] Israel21c, "Israeli-Developed Chemical Laser Lauded as Significant Breakthrough for 2003."
[339] "International Pair To Develop Laser-based DIRCM Anti-MANPAD Solution**,"** *Defense Daily International* 8, no. 25, June 22, 2007 (via Proquest).
[340] PR Newswire, "Elettronica and Elbit Systems Electro-Optics Elop Generating a Joint Laser-Based DIRCM Product," June 21, 2007 (via Proquest).
[341] "MBDA, IAI Sign Missile Defense Accord," Israel Aircraft Industries Web site, July 22, 2004, http://www.iai.co.il/site/en/iai.asp?pi=23048&doc_id=32390.
[342] "MBDA."

consumer of Israeli-manufactured weapons.[343] Israel's regional strategic ally Turkey has also shown interest in purchasing the Arrow.[344]

Offensive Missile Technology

In addition to an array of missile countermeasures, Israel has developed substantial offensive missile capabilities, with missiles that can deliver both conventional and unconventional weapons. Israel began to produce its Jericho series of ballistic missiles in the 1970s. This missile would serve as the delivery vehicle for Israel's nuclear warheads. A test program for the missile series operated at a remote facility in South Africa until the early 1990s, when Israel's close strategic cooperation with South Africa ended. Now Israel tests its missiles at the Israeli air force's missile test range at Palmahim Air Force Base on the Israeli Mediterranean coast, where all tests are visible. Three major designs of the Jericho missile have been built to date, Jericho I, II, and III (see table 13 for technical specifications for the Jericho and Israel's other offensive missiles). The Jericho II series, in service since the mid-1980s, has a confirmed range of 1,500 kilometers, which brings the entire Middle East within Israel's range, including, notably, Iran. The latest missile design, the three-stage Jericho III, has a range, depending on the estimate, of between 4,500 and 7,800 kilometers, and is capable of delivering either conventional or unconventional payloads, including multiple warheads weighing 750 to 1,300 kilograms. The Jericho III, probably in service since mid-2005, is thought to be the missile that Israel tested on January 17, 2008. Some believe that the missile can reach any point on earth, giving it the capability to warrant the label of intercontinental ballistic missile (ICBM). At a minimum, the Jericho III can reach Africa, Europe, and most of Asia.[345]

[343] "Report—India, Israel Expected to Strike 'Several More Deals' in Defense Sector," *New Delhi Force*, March 11, 2005 (FBIS (now OSC) Document SAP20050311000078).
[344] Center for Defense Information (CDI), "CDI Missile Defense Update #3, 2006," February 24, 2006, http://www.cdi.org/friendlyversion/printversion.cfm?documentID=3331.
[345] Anthony H. Cordesman, "Weapons of Mass Destruction in the Middle East: Regional Trends, National Forces, Warfighting Capabilities, Delivery Options, and Weapons Effects" (Washington, DC: Center for Strategic and International Studies, April 15, 2003), 39, http://www.iraqwatch.org/perspectives/csis-middleeast_wmd-041503.pdf.

Table 13. Israel's Launched Systems and Deployment Capabilities

Designation	Type (definitions below*)	Missiles	Range (km)	Payload	Motors	Status
Delilah Derivative (Star–1)	ALCM	NA	400	450	Turbojet	In development
Jericho I	SRBM	~50	500	750	Solid	In service
Jericho II	MRBM	~100	1,500	1,000	Solid	In service
Jericho III (extended range)	MRBM IRBM ICBM		2,000– 4,800– 11,500	1,000	Solid/ liquid	In development
Modular Stand-Off Vehicle	ALCM	NA	100	675	None	In development
Popeye Turbo	ASM		350	895	Turbojet	

*ALCM = Air-launched cruise missile.
ASM = Anti-ship cruise missile.
ICBM = Intercontinental ballistic missile, 5,500 km +.
IRBM = Intermediate-range ballistic missile, 3,000–5,500 km.
MRBM = Medium-range ballistic missile, 1,000–3,000 km.
SRBM = Short-range ballistic missile, 70–1,000 km.

Source: Based on Andrew Feickert, "Missile Survey: Ballistic and Cruise Missiles of Selected Foreign Countries," *CRS Report for Congress*, RL30427, updated July 26, 2005, http://www.fas.org/sgp/crs/weapons/RL30427.pdf.

In addition to ballistic missile technology, Israel maintains a fleet of Dolphin-class submarines, widely suspected of being armed with Israeli-made medium-range (1,450 km) cruise missiles capable of carrying nuclear as well as conventional warheads.[346]

Aerospace: Military and Civilian Priorities

In addition to missiles, missile countermeasures, and UAVs, space technology is a third major area of military technology in which Israeli R&D has recently produced breakthroughs. Israel's expertise in space encompasses two main space technologies, intelligence and communications, the two most popular domains in the world space market.[347] Israel's space

[346] Cordesman, "Weapons of Mass Destruction in the Middle East," 40.
[347] Amnon Barzilay, "Advanced Military Satellites Unveiled," *Ha'aretz* on-line edition, August 3, 2003 (in "Space Program Director: Israel Develops 3 Intelligence Satellites Simultaneously" (FBIS (now OSC) Document GMP20030803000069).

efforts are mainly directed to the development of high-resolution-imaging satellite-borne capabilities, primarily for military reconnaissance but increasingly also for civilian use.[348] Currently, a number of Israeli imaging satellites are operating in space, and Israel is considered a leader in the field of small satellites for high-resolution remote sensing. In addition, Israel has put major emphasis on communications satellites suitable for military use.[349] Over the next two decades, Israel plans to deploy additional communications and imaging satellites, including imaging radar spacecraft, and is considering a system that would allow launch-on-demand of small satellites from fighter aircraft.[350] Israel's capabilities in commercial communications satellites are of increasing importance, as are its commercial satellites with their high-resolution electro-optical cameras, which provide commercial digital imagery services. In recent years, an increasing number of Israeli companies in the private sector have entered the imaging and communications markets.[351]

Launch Capabilities for Space

To support its capabilities in satellites, Israel has an independent space-launch capability and is one of only a handful of nations to have such a capability. In September 1988, Israel became the ninth nation to launch a satellite, when a Shavit launcher, resembling the Jericho missile, placed the Ofek 1 satellite into orbit.[352] This launch was the first achievement of the Israeli space program, which was established in 1981, and the Israel Space Agency (ISA), founded in 1983 under the Ministry of Science.[353] Originally motivated mainly by military needs, primarily intelligence, the Israeli space program was funded through a special budget in the Ministry of Defense and borrowed from, and contributed to, defense technologies.[354] The Shavit series of launchers, which provides ground-based launch capabilities for satellites, continues to improve its lift capacity. Developed by IAI, Israel's lead contractor for satellite

[348] Amnon Barzilay, "Shavit's Ofek Launch Proves It Can Lift Satellites—and Weapons—Say Experts," *Ha'aretz* on-line edition, April 5, 2004 (FBIS (now OSC) Document GMP20040405000053).
[349] Barbara Opall Rome, "Israel Makes Plans for Broad Space Capabilities," *Space News*, August 25, 2003, http://www.space.com/spacenews/spacenews_businessmonday_030825.html.
[350] International Network of Engineers and Scientists Against Proliferation Web site, http://www.inesap.org/bulletin25/#a6 (accessed March 4, 2008).
[351] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."
[352] Barzilay, "Shavit's Ofek Launch Proves It Can Lift Satellites."
[353] Barzilay, "Advanced Military Satellites Unveiled."
[354] Arieh O'Sullivan, "Israel Air Force Changes Its Name," *Jerusalem Post*, January 1, 2004, in "Israeli Air Force 'Unofficially' Changes Name to Israel Air and Space Force'" (FBIS (now OSC) Document GMP20040130000052).

systems, the Shavit launchers are capable of putting into low-Earth orbit satellites weighing from 100 to 500 kilograms.[355] The three-stage solid fuel Shavit rocket is mobile, in that its launch preparation equipment is independent of the launch site, allowing the launch of satellites from different launch locations, according to user requirements.[356] However, the launchers' lift capacity remains a limitation, especially in view of Israel's unique practice of launching westward against the Earth's rotation on safety and security grounds, at the sacrifice of the extra thrust that the Earth's rotation can provide in eastward launches.[357] Israel's planned larger satellites, which are expected to weigh more than two tons, will have to be launched by a non-Israeli launch system.[358]

A future derivative of the current Shavit missile, the LK–1 from the Leolink program, is expected to be able to lift heavier payloads to higher orbits, for instance, 350-kilogram-class satellites into 700-kilometer circular polar orbits. The Leolink program, announced in 2002, was begun in order to enable Israel to market launch services.[359] Since 2002, Israel has discussed with Brazil the possibility of using its Alcântara launch site for the Leolink line, in order to maximize the boost provided by eastward launches at the equator.[360] In the meantime, Israel launches from its own facility near the Palmachim Air Force Base, south of Tel Aviv.[361]

Another ambition that Israel has for future launch capabilities is to develop technology to allow launch from jets. Scientists at Rafael Armament Development Authority are examining technology to launch satellites from F–15 fighter jets, for example. The idea would be to upgrade the Black Sparrow missile—the missile target in tests of the Arrow system—with a more powerful engine, and to carry a microsatellite in the missile's nose.[362] As of 2003, Israel anticipated having this technology available after 2008.[363] Also as of 2003, Israeli policymakers expected that within five years the Israeli air force would be able to launch multiple small

[355] "Air & Cosmos's 'Confidential' News for 2 May 2003," *Air & Cosmos* (Paris), May 2, 2003 (FBIS (now OSC) Document EUP20030507000500).
[356] "Israel's Shavit Launches SpySat Along Retrograde Flight Profile," *Space Daily*, May 28, 2002, http://www.spacedaily.com/news/eo-02s.html.
[357] "Israel's Shavit Launches SpySat Along Retrograde Flight Profile."
[358] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."
[359] "Air & Cosmos's 'Confidential' News for 2 May 2003."
[360] "Air & Cosmos's 'Confidential' News for 2 May 2003."
[361] "Space Rocket Launch Sites Around the World," *Space Today*, 2004, http://www.spacetoday.org/Rockets/Spaceports/LaunchSites.html#Palmachim.
[362] Arye Egozi, "A Satellite for Every Commander," *Yedi'ot Aharonot* (Tel Aviv), July 9, 2003, in "Israel: Development of Micro-Satellites, SAR's Viewed" (FBIS (now OSC) Document GMP20030709000164).
[363] Egozi.

satellites—satellites weighing less than 100 kilograms—on demand from fighter aircraft.[364] In 2005, a more pessimistic timeframe of 10 to 20 years was suggested.[365]

Satellites: Seeking Full-Spectrum Capabilities

Israel has three primary satellite families: Ofek (or Ofeq), Eros, and Amos. The Ofek series of high-resolution imaging satellites is used solely for military intelligence purposes. The dual-use, remote-sensing Eros series provides one-meter-resolution images for both defense and commercial purposes.[366] The Amos series consists of communications satellites. One of Israel's ambitions for future space programs is to create imaging satellites in a wide spectrum of wavelengths.[367] Israel's military users want the ability to make images in all light and weather conditions. To satisfy this requirement, the Ministry of Defense aims to exploit the full spectrum of imaging capabilities, including increasingly high-resolution electro-optics, infrared, synthetic aperture radar (SAR), hyper-spectral, and three-dimensional mapping.[368]

TechSAR: Israel's 2008 Expansion of Its Imaging Options to Include Imaging Radar

Israel's latest and most complex satellite expands the country's imaging options with the use of imaging radar. In addition to its current electro-optical imaging satellites, Israel has developed, under the brand name of TechSAR, a demonstrator satellite equipped with SAR. The 250-kilogram SAR-equipped satellite was placed in orbit on January 21, 2008, from southeast India on an Indian Polar Satellite Launch Vehicle.[369] The launch was carried out by a joint Indian–Israeli team in accordance with a cooperation agreement on space activities between the government of India and IAI, TechSAR's prime contractor.[370]

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[364] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."
[365] Barbara Opall Rome, "Israeli Firms Join Forces on Microsatellites—Business Venture Fueled by Ministry of Defense Space Plans," *Space News*, October 3, 2005, http://www.space.com/spacenews/archive05/IAI_100305.html.
[366] "Israel Releases Satellite Capabilities," *Middle East Newsline* 5, no. 232, June 20, 2003 (via Proquest).
[367] Barbara Opall Rome, "Israel Puts Air Force in Charge of Space Activities—Hotly Debated Decision Renames the Service the Israel Air and Space Force," *Space News*, February 20, 2006, http://www.space.com/spacenews/archive06/IZ_022006.html.
[368] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."
[369] Yossi Melman, "Satellite Launch Bolsters Ability to Spy on Tehran," *Ha'aretz*, January 21, 2008, http://www.haaretz.com/hasen/spages/946750.html.
[370] Melman.

The TechSAR is the first satellite of its kind developed in Israel and ranks among the world's most advanced space systems. According to Elta Systems, Ltd., Israel's leading radar development house, which developed the SAR payload, that payload is capable of "producing high resolution radar images which approach photographic quality and operate as true all-weather, day and night sensors capable of penetrating clouds, rain, smoke and a variety of man-made camouflage."[371] The satellite is controlled and monitored by an IAI-based ground station.

The TechSAR joins a notable list of Israeli satellites, most developed, produced, and launched for the Ministry of Defense by IAI's space division, with contributions from other divisions, as well as from other leading high-tech companies such as Elta, IMI, Raphael, Rokar, and Tadiran–Spectralink. As of TechSAR's launch in 2008, Israel had launched 11 Ofek, EROS, and Amos satellites, seven of which remain in orbit.[372]

Ofek: Israel's Spy Satellites, Optical Remote Sensing

The latest version of the Ofek electro-optical satellite series, the Ofek 7 reconnaissance satellite, was launched on June 11, 2007, from Israel's test range at Palmahim Air Force Base on a Shavit launch vehicle.[373] The Ofek 7 represents a new generation of optical remote sensing with extremely high resolutions. In describing the satellite's imaging power, the director of space programming at the Ministry of Defense's Research and Development Directorate said that its resolution was approaching the so-called defraction limit where light is defracted to a point where pictures cannot be captured. In his words, "The defraction limit for visual range is close to 10 centimeters resolution. We're getting better resolutions all the time and getting closer to the limit, but we don't disclose details."[374] He added that Ofek 7 "improved Israel's operational capabilities by dozens of percent."[375]

The 660-pound Ofek 7 spy spacecraft went into a 193- by 372-mile orbit with a focus on Iran, Iraq, and Syria. Ofek 7 replaces the Ofek 5 electro-optical satellite, launched from Israel in 2002. It brings Israel's space-based reconnaissance program back to full strength following the 2004 loss of the Ofek 6 reconnaissance satellite as a result of a malfunction in the Shavit

[371] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."
[372] Melman.
[373] Frank Morning, Jr., "Israel Overhead: Israel Launches New Recce Satellite," *Aviation Week & Space Technology* 166, no. 23, June 18, 2007 (via Proquest).
[374] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."
[375] Opall Rome, "Israel Makes Plans for Broad Space Capabilities."

launcher. The Ofek 6 was intended to provide additional depth to Israel's missile warning system, as well as real-time data on Iran's missile program.[376]

EROS: Dual-Use Imaging Satellites

One of the off-shoots of the development of the Ofek military imaging satellites is the Eros—Earth resources observation satellite—series of civilian or dual-use imaging satellites. As of 2008, Israel is operating two of the advanced Eros imaging spacecraft. The second in the Eros series, the civilian Eros B, was launched under contract to Israel's military in April 2006 from a Russian launch site.[377] The Eros B, designed and built by IAI, delivers a 70-centimeter ground resolution and is used to photograph Iran's nuclear sites. The satellite also produces photographs that are sold on the civilian market and are part of Israel's yearly security exports.[378]

Israel's Ministry of Defense reportedly offered India the services of the dual-use Eros A in December 2003, at the same time that Israel was considering an Indian offer to lease the Israeli Ofek 5 military satellite.[379] The Israeli satellite company ImageSat International provided the European Union Satellite Center with remote-sensing imagery from the Eros A in 2004; the imagery was for both civilian and military applications.[380]

Amos: Military Communications Satellites

In addition to its imaging satellite series, Israel has developed a series of military communications satellites, the Amos series.[381] The latest in the series, the Amos 4, is under development by IAI. Currently planned for launch in 2010, Amos 4 will provide the Ministry of Defense with a dedicated, secure communications satellite. The Amos 4 communications satellite is a larger and more capable version of the Amos 2 commercial communications

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[376] Hanan Grinberg, "Spy Satellite Launch Fails," *Ynet* online edition, September 6, 2004, in "Israeli-Made New Spy Satellite Launch Fails, Satellite Crashes Into Sea" (FBIS (now OSC) Document GMP20040906000124).
[377] Justin Ray, "Israeli Satellite Rides Russian Soyuz into Space," *Spaceflight Now*, December 27, 2003, http://www.spaceflightnow.com.
[378] Tel Aviv Workshop for Science, Technology, and Security, "Israel in Space," April 14, 2005, http://spirit.tau.ac.il/government/downloads/spaceenglish.pdf.
[379] James Martin Center for Nonproliferation Studies (CNS), "Current and Future Space Security: Israel," n.d., http://cns.miis.edu/research/space/India/mil.htm (accessed January 17, 2008). Hereafter cited as CNS.
[380] "Israeli Satellite Firm Signs Deal with EU To Provide Civilian, Military Imaging," *Middle East Newsline*, March 3, 2004 (FBIS (now OSC) Document GMP20040303000233).
[381] "Space Systems: Communication Satellites: Amos HP," Israel Aircraft Industries Web site, http://www.iai.co.il/site/en/iai.asp?pi=14469&doc_id=15686.

satellite, which was launched from Kazakhstan in late 2003. Because the new satellite is twice the size of Amos 2—too large for Israel's Shavit launcher—its launch will require the services of an outside provider.[382] Israel has also developed the Amos 3, scheduled for launch in 2008, which will augment the overall communication capacity of the satellites currently deployed.[383]

Israel's Vision for Future Military Satellites: Formation Flying and Modular Payloads

Adding to its current four satellite types—Amos, Eros, Ofek and TechSAR—Israel has plans to explore a number of other possibilities for future military space endeavors. Most notably, Israel's current ambitions for space include the creation of constellations of small, modular satellites capable of working as a team. Israel's emerging concept of such constellations—a version of what the international aerospace community labels formation-flying—calls for dividing payloads and particular mission roles among a number of interacting satellites, so the sum of the cluster exceeds the contribution of each individual spacecraft.[384] In such clusters, as described by specialists at the Technion, the single satellites would maintain continuous communication and operational links with each other. The concept of such operational clusters remains largely theoretical thus far, and clusters have not been deployed for military purposes. Nonetheless, according to the head of space programs in Israel's Ministry of Defense, Israel foresees deploying effective satellite clusters with shared communications, signals, and other payloads within a decade.[385]

In addition to satellite constellations, the Ministry of Defense is pursuing developments involving a low-cost, multi-mission, satellite bus, the physical and electrical infrastructures that support a payload. According to this vision, the military would hold in inventory a number of common satellite buses—each costing US$10 to US$12 million—whose modular payloads could be deployed for specific missions, depending on need. Military users would have the capability to reprogram satellites for different missions through software uplinked directly to satellites already in orbit. Such a system, according to Haim Eshed, the head of Israeli space programs,

[382] "Space Systems: Communication Satellites."
[383] Felix Frisch, "We Are No Longer Just a Curiosity," *Rishon Leziyyon Globes (Ha'erev Supplement*), June 4, 2004, in "Israeli Firm's Plans for Additional Amos Communications Satellites Viewed" (FBIS (now OSC) Document GMP20040604000146).
[384] Barbara Opall Rome, "Israel To Greatly Expand Space Capabilities," *Defense News* 22, no. 24 (June 11, 2007), http://www. defensenews.com.
[385] Opall Rome, "Israel To Greatly Expand Space Capabilities."

could be in operation within a decade.[386] Another near-term possibility that he envisions is the use of fighter aircraft by the Israeli air force to launch on demand multiple satellites ranging in weight from tens of kilograms to 100 kilograms.[387]

In pursuing such ideas as constellations of satellites, modular and multi-mission satellites, and new modes of satellite delivery and control, Israeli policymakers aim to achieve performance levels currently possible only for larger satellites. This focus on small, lightweight satellites—a focus partly dictated by launch constraints and partly by finances—could enable Israel to realize its aspiration for launching self-sufficiency.[388] Thus, Israel is expected to maintain and extend its investments in low-cost microsatellite and nanosatellite capabilities.[389]

The magnitude of these investments is subject to fluctuation, as demonstrated by funding cuts for satellites imposed in 2004.[390] Currently, Israel's budget for military and civilian space remains very modest, at an estimated US$60 million per year.[391] Given Israel's current population of about 7 million people, that level of annual spending compares with that of Austria, Belgium, and Denmark, whose respective annual budgets run from about US$6 to US$11 per capita. In comparison, the United States spends some US$110 per capita annually. Israel's space establishment, whose ambitions for space would place Israel among the world's top-five space-faring nations, aspires to an annual budget of between US$150 and US$200 million.[392]

International Space Cooperation

The major means by which Israel circumvents resource constraints in its space program is through cooperation with other countries. A noteworthy example of international space cooperation is Israel's membership in the European Space Agency. This membership allows

[386] Opall Rome, "Israel To Greatly Expand Space Capabilities."
[387] Egozi.
[388] Egozi.
[389] Barbara Opall Rome, "Israel Invests Research Funds to Develop Light Minisatellites," *Space News*, January 24, 2000, http://www.space.com/spacenews/archive00/sn2000.fff994.html.
[390] Barbara Opall Rome, "Israel's Military Cuts Satellite Funds," *Defense News* 19, no. 28 (July 19, 2004): 26 (via Proquest).
[391] Barbara Opall Rome, "Israel Wary of China ASAT Test," *Defense News* 22, no. 5 (February 5, 2007), http://www.defensenews.com/story.php?F=2527890&C=mideast.
[392] Opall Rome, "Israel Wary of China ASAT Test."

Israel to participate in European space projects and to submit proposals for joint projects.[393] In 2004 Israel signed an agreement to participate in Galileo, the European global navigation satellite system project.[394] Under the agreement, Israel is expected to contribute approximately US$30 to US$50 million to the project. In addition, Israel has established many formal bilateral scientific and technological research agreements with countries such as France, Germany, the Netherlands, Russia, and the United States.[395] Israel also has significant cooperative arrangements with non-Western countries, most notably, India. In 2002 India and Israel signed an umbrella agreement for ongoing cooperation in the peaceful uses of space.[396]

Israel Contemplates Antisatellite and Other Space Warfare Capabilities

As Israel continues to develop its imaging and communications satellites for both military and civilian use, some in the defense establishment leadership have begun to urge that Israel develop technologies to counter possible future threats to its space assets, as well as threats from space.[397] A number of Israel's top defense planners warn of the potential for the proliferation of antisatellite (ASAT) capabilities in the hands of regional adversaries, for example, space-based or ship-based antisatellite missiles or satellite-attacking lasers and jammers. These officials advocate the development of defensive capabilities to protect Israel's deployed satellites against weapons that could paralyze them. Others go further, recommending that Israel itself develop and deploy offensive capabilities in the form of ASAT weapons. Such weapons would address the future potential of the acquisition by enemies of high-resolution remote-sensing satellites that could allow the accurate targeting of sites within Israel.[398]

In urging the development and deployment either of defensive or offensive space warfare capabilities, advocates have met with considerable resistance among other Israeli defense

[393] Amnon Barzilay, "Israel to Participate in ESA Space Projects," *Ha'aretz* on-line edition, June 19, 2003, in "Israel to Participate in ESA Space Projects, New Weapons Unveiled" (FBIS (now OSC) Document GMP20030619000032).
[394] "Israel Joins Galileo," *Intelligence Online*, March 26, 2004, in "Israel To Take Part in European Galileo Project" (FBIS (now OSC) Document EUP20040329000444).
[395] Israel, Ministry of Foreign Affairs, "Israel's Space Program," http://www.mfa.gov.il/mfa/mfaarchive/2000_2009/2003/6/Israel-s%20Space%20Program.
[396] N. Gopal Raj, "India, Israel Yet to Work Out Specifics of Space Cooperation," *The Hindu* online edition, September 10, 2003, http://www.thehindu.com/2003/09/10/stories/2003091002221100.htm.
[397] Barbara Opall Rome, "Israeli Official Urges Space-Based Weapons," *DefenseNews.com*, January 11, 2005, http://www.serve.com/vanunu/nukes/20050111defensenews.html.
[398] Barbara Opall Rome, "Israeli Experts Urge Development of ASAT Weapons," *Space News*, February 1, 2005, http://www.space.com/spacenews/archive05/israelarch_013105.html.

planners. Critics argue that the expenditure of scarce space resources for a more militarized space program is currently unnecessary, given Israel's large technological advantage in space over its non-space-faring regional adversaries. Many see more pressing priorities in the realm of space, and hold that it would be premature to lobby for the levels of investment that would be required for major new weapon systems, such as ASAT. In addition, some of Israel's current plans for space would already provide a measure of security and protection with respect to Israel's space assets. The launch-on-demand idea, for example, could ensure the rapid replacement of damaged satellite capabilities.[399]

One consideration that seems largely absent from the current public discussion in Israel of space warfare capabilities is the international community's possible reaction to Israeli proposals to step up the militarization of space. Israel's avowed commitment to limiting such militarization has long been weaker than that of many other nations. More than 150 nations, including Canada, China, Russia, and members of the EU, are pressing for a permanent ban on weapons in space that goes well beyond the 1967 Outer Space Treaty (OST). That treaty first codified "the peaceful use of outer space" and outlawed military bases or weapons of mass destruction in orbit. Regular attempts since 1967 to update the treaty to include ASAT and other space-based weapons remain unsuccessful, largely because of opposition from the United States, which Israel appears to second.[400] Although Israel is a member of the OST, it abstains from United Nations General Assembly votes on the prevention of an arms race in outer space (PAROS) resolution of 1968. These abstentions make Israel, as one analyst put it, "one of the very few nations of the world that routinely abstains from voting for a resolution to ban weapons in space."[401] Israel's stance on space arms control is in keeping with its stance on arms control in general. For example, Israel is not a member of the Partial Test Ban Treaty or the Comprehensive Test Ban Treaty (see table 14).[402]

[399] Opall Rome, "Israel Wary of China ASAT Test."
[400] Opall Rome, "Israeli Official Urges Space-Based Weapons."
[401] Opall Rome, "Israeli Experts Urge Development of ASAT Weapons."
[402] CNS, "Current and Future Space Security, Israel."

Table 14. Israel's Participation in Major Multilateral Arms Control Agreements and Treaties

	Signed	Ratified
Biological Weapons Convention	- - -	- - -
Chemical Weapons Convention	1993	- - -
Comprehensive Test Ban Treaty	1996	- - -
Convention on Certain Conventional Weapons (Israel is party to three of the five protocols.)	- - -	1995
Nuclear Non-Proliferation Treaty (NPT) (Israel is suspected of developing nuclear arms outside the treaty.)	- - -	- - -
Ottawa Mine Ban Convention	- - -	- - -
Outer Space Treaty	1967	1977
Source: Based on Arms Control Association, "Arms Control and Proliferation Profile: Israel," November 2007, http://www.armscontrol.org/factsheets/#1.		

Israel's Nuclear Technology and Chemical and Biological Weapons (CBW) Capabilities

Israel keeps its distance from many of the international community's arms control agreements, in part because Israel itself possesses or aspires to possess some of the capabilities they proscribe.

Israel's Nuclear Capabilities

Four decades ago, Israel became the world's sixth nuclear armed power, and now it ranks as probably the sixth-largest nuclear power in the world.[403] Israel's Negev Nuclear Research Center at Dimona began operations in the mid-twentieth century and is capable, with its 150-megawatt heavy-water reactor and plutonium reprocessing plant, of producing weapons-grade nuclear material.[404] Israel developed nuclear weapons with French help in the 1950s and 1960s, and, since the Nixon administration, it has had the tacit approval of the United States to continue their development.[405]

[403] Federation of American Scientists, "WMD Around the World: Nuclear Weapons, Israel," January 8 2007, http://www.fas.org/nuke/guide/israel/nuke/index.html.
[404] Center for Defense Information, "The World's Nuclear Arsenals," February 4, 2003, http://www.cdi.org/issues/nukef&f/database/nukearsenals.cfm.
[405] Until the French imposed their weapons embargo on Israel because of the Six-Day War, Israel and France cooperated in defense-related research projects, including their nuclear programs. France licensed the technology developed at the Weizmann Institute for the production of heavy water and, in return, assisted Israel in building its nuclear reactor.

Israel is not a signatory to the Nuclear Non-Proliferation Treaty—one of only four non-signing countries, along with Cuba, India, and Pakistan—and does not subject its core nuclear weapons facility at Dimona to monitoring by the International Atomic Energy Agency (IAEA). (Another five-megawatt research reactor at Nahal Soreq near Beersheba is under IAEA supervision and safeguards).[406] Although Israel maintains a policy of "strategic ambiguity," neither admitting nor denying that it has nuclear weapons, the country's possession of nuclear weapons is well-known. In 1986 whistle blower Mordechai Vanunu revealed some of the technical capabilities of the nuclear program to the London *Sunday Times*.

The size, if not the existence, of Israel's nuclear arsenal is a matter of debate. By most estimates, Israel has 100–200 nuclear weapons. However, some experts, such as *Jane's*, estimate that Israel has up to 300 nuclear weapons of various types.[407] Additional warheads may be available for free-fall bombs and artillery projectiles.[408]

As for delivery systems, Israel, as noted, evidently has a nuclear triad comprising air-based, land-based, and sea-based components, with land-based ballistic missiles, especially the Jericho, the primary means of delivery. The Shavit satellite launch vehicle, used for inserting objects into low-Earth orbit, can also be adapted for a long-range nuclear delivery role. Converted into a ballistic missile, the space booster would have an intercontinental ballistic missile range.[409] With regard to airborne delivery systems, the Israeli air force's U.S-supplied F–16 squadrons can be equipped to carry nuclear warheads, as can the U.S.-supplied F–4Es, F–15s, and Jaguars.[410] For another type of airborne delivery, the Israelis have reportedly modified conventional air-to-surface missiles to deliver nuclear warheads. Regarding seaborne systems, Israel may have the capability of delivering nuclear weapons by cruise missile—the Popeye turbo cruise missile with a range of 1,500 kilometers—from submarines. In November 2005, Israel acquired the final two of its five German-made Dolphin-class submarines, which cost

[406] CNS, "Israel: Weapons of Mass Destruction—Capabilities and Programs," cns.miis.edu/research/wmdme/israel.htm.
[407] John Eldridge, ed., *Jane's NBC Defence Systems*, 1999–2000, 12th ed. (Surrey, UK: Jane's Information Group, 2001), 27.
[408] Cordesman, "Weapons of Mass Destruction in the Middle East," 40.
[409] Cordesman, "Weapons of Mass Destruction in the Middle East," 44.
[410] John Chipman and Christopher Langton, eds., *The Military Balance 2004–2005*, The International Institute for Strategic Studies (London: Oxford University Press, 2004), 126–27.

US$340 million to US$500 million each.[411] The submarines, thought to be modifiable to carry nuclear-tipped cruise missiles, are presumably meant to add sea-based capability to complete the nuclear triad (air, ground, sea) for Israel.[412] The sea-based capability provided by the submarines could afford Israel a second-strike capability, by permitting the survival of some of Israel's nuclear weapons following a nuclear attack on Israel. However, while the submarines theoretically could be modified to launch nuclear weapons via cruise missiles, some observers doubt the technical feasibility of doing so.[413]

Besides strategic nuclear capabilities, Israel is also widely believed to possess a tactical nuclear capability, including small nuclear landmines, and strategic nuclear warheads that it can fire from cannons. The army has also developed a nuclear projectile for its 175-millimeter self-propelled gun. In addition, according to several accounts, the Israelis have developed low-yield neutron bombs able to destroy troops with minimal damage to property.[414] Some have speculated that the Israelis will update their nuclear arsenal to "micronukes" (with an explosive yield of 100 tons) or "tinynukes" (with an explosive yield of 1,000 tons) capable of striking point targets.[415] These could be used to attack hardened buried command-and-control facilities or to destroy airfields without exposing Israeli pilots to combat.[416] One Israeli military analyst has speculated that Israel is also pursuing an R&D program to equip missiles with multiple independently targetable reentry vehicles (MIRVs).[417]

[411] Walter Pincus, "Israel Has Sub-Based Atomic Arms Capability," *Washington Post*, June 15, 2002, http://www.washingtonpost.com. According to Pincus, Israel obtained the submarines through a compensation package from the German government following the 1990–91 Persian Gulf War, during which Israel suffered economic losses from Iraqi Scud missile attacks. The German government, led by Chancellor Helmut Kohl, granted Israel two submarines and split costs for a third.
[412] Douglas Frantz, "Israel's Arsenal Is Point of Contention," *Los Angeles Times*, October 12, 2003, http://www.latimes.com. See also Barbara Opall Rome, "Berlin Nixes Israeli Request for Free Subs," *Defense News* 19, no. 24 (June 14, 2004), http://www.defensenews.com.
[413] "Israel: German Subs and Nuclear Reach," *Stratfor: Global Intelligence Brief*, November 22, 2005, http://www.stratfor.com.
[414] Seymour M. Hersch, *The Samson Option: Israel's Nuclear Arsenal and American Foreign Policy* (New York: Random House, 1991), 223.
[415] Thomas W. Dowler and Joseph H. Howard II, "Countering the Threat of the Well-Armed Tyrant: A Modest Proposal for Small Nuclear Weapons," *Strategic Review* 19, no. 4 (Fall 1991), 34–40.
[416] Harold Hough, "Israel Reviews its Nuclear Deterrent," *Jane's Intelligence Review* 10, no.11 (November 1998), 11–13.
[417] Martin van Creveld, *The Sword and the Olive. A Critical History of the Israeli Defense Force* (New York: Public Affairs, 1998), 174.

Chemical and Biological Weapons

Israel has strong research capabilities relevant to both defensive and offensive chemical and biological weapons (CBW), and probably has some weaponized agents, as well as defenses against them.[418] However, Israel's CBW capabilities are difficult to characterize. Clues to Israel's policy stance reside in the fact that Israel has signed but not ratified the Chemical Weapons Convention; has not signed the Biological Weapons Convention; and does not issue public policy statements about its capabilities.[419] Israel also maintains strict security and secrecy in connection with the installation that hosts its CBW program, the Israeli Institute for Biological Research (IIBR) at Nes Ziona. The IIBR facility, which is analogous to Dimona for the nuclear program, has been deleted from aerial survey photographs and maps and replaced with orange groves. This secrecy is reinforced by military media censorship concerning the facility and proscriptions on on-site international scrutiny.

Assessments of Israel's CBW capabilities necessarily rely on anecdotal evidence, intelligence leaks, and carefully vetted releases of information, for example, on IIBR's Web site. There have been numerous allegations since the beginning of the Israeli state of its use of both biological and chemical agents. The allegations include the poisoning of wells in the 1950s with cholera or typhoid to deter the return of former Arab inhabitants and the use more recently of chemical defoliants and nerve gases. In 1992 a crash of an El Al plane in Amsterdam released the U.S.-supplied ingredients of sarin gas that were destined for the IIBR.[420]

Another basis for gauging Israel's capabilities is information put out by Israel itself, for example, on the IIBR Web site, which describes the institute's various divisions and research activities involving potential CBW agents. The institute carries out investigations of such topics as viral and bacterial diseases, the genetic determinants of virulent traits, diagnostic assays, and biosensors and detectors. The institute's Web site highlights those activities that are relevant to a defensive CBW mission, such as the development of vaccines and biosensors, as well those that serve non-military purposes, such as research on Alzheimer's disease. This slanted presentation

[418] Avner Cohen, "Israel and Chemical/Biological Weapons: History, Deterrence, and Arms Control," *The Nonproliferation Review*, Fall–Winter 2001, 27–53, http://www.nti.org/e_research/profiles/Israel/Biological/3652.html.
[419] Cohen.
[420] Cohen.

precludes using the Web site alone to answer the question of whether or not Israel has offensive biological warfare or chemical warfare programs. As one analyst stated,

> Israel's motivations in the CBW fields, defensive or offensive, cannot be inferred merely from the existence of research activities involving potential CBW agents … [because of] the intrinsic ambiguity that characterizes basic research on dangerous pathogens. Such research may be relevant to offensive BW but also have "legitimate" applications in medicine and agriculture. With respect to studies of bacterial or viral pathogenesis, it can be difficult to determine whether the intent of a particular research project is to create a "defensive" capability (e.g., vaccine development) or an "offensive" one (e.g., engineering more virulent strains). Because of this intrinsic ambiguity, Article I of the BWC does not ban basic research … [D]evelopment directly related to weaponization is prohibited.[421]

Despite the intrinsic ambiguity of research in chemical and biological warfare programs and the spottiness of evidence, "a near-consensus exists among experts," according to the same analyst, that Israel has developed, stockpiled, and perhaps even deployed, chemical weapons. Somewhat less certainty exists about biological weapons. The U.S. government does not include Israel in its public list of states with an offensive biological weapons capability, although it may be one of the two unnamed states on the list. The Office of Technology Assessment for the U.S. Congress, on the other hand, has stated that Israel is "generally reported as having an undeclared offensive biological warfare program," as well as undeclared offensive chemical warfare capabilities.[422] Anthony Cordesman of the Center for Strategic and International Studies states that Israel not only has conducted extensive research into gas warfare but also is ready to produce biological weapons.[423] None of the analysts of Israel's CBW programs are able to assess with certainty the degree to which some of Israel's CBW work has "legitimate applications" in medicine or agriculture.

Civilian/Commercial Spin-offs of Israel's Military Technologies

There is no question that Israel's defense sector as a whole has been and remains an important source of spillovers into the civilian economy. Indeed, commercial/civilian spin-offs

[421] Cohen.
[422] Cited in Cohen.
[423] Anthony Cordesman, *Perilous Prospects: The Peace Process and the Arab-Israeli Military Balance* (Boulder, Colorado: Westview Press, 1996), 118.

from the military field laid the basis for Israel's first generation of high-tech enterprises and accounted in no small part for the very emergence of Israel as a high-tech cluster.

The Israeli push for military self-sufficiency that began with the French weapons embargo after the 1967 Six-Day War was a stimulus for computer and electronics training and R&D within the military—in particular its special elite computer units. In addition, improved weapons, intelligence gathering, and control systems from the defense industry required advances in electronics, software, telecommunications, and process control. When the effort for military self-sufficiency reached its limits in the 1980s, Israel was left with a strong edge in technologies and skills. As a result, Israeli industries were well positioned to respond to the civilian demand that was about to explode in the U.S. market for personal computers and network and Internet products. Thanks to various kinds of Israeli government assistance to would-be S&T entrepreneurs and innovators displaced from the military sector in the late 1980s, and thanks to intimate linkages with Silicon Valley, technology originally developed by the IDF or Israel's defense industries served as the basis for many civilian high-tech products developed by non-military companies in the country's nascent high-tech cluster. In particular, Israelis became strong in commercial applications for niche technologies in the telecommunications and Internet-related industries. Most notably, military solutions to the problems of network security gave birth to civilian versions of the solutions, such as the firewall. In addition, in the words of one analyst,

> From military R&D came voice compression, DSP chips, streaming techniques, faster network devices (some of which rely on electro-optical innovations), faster network software, Virtual Private Networks, internet telephony software (an innovation that began in Israel), and network performance products.[424]

Another analyst, writing in 1999, listed 10 direct military-to-commercial applications that occurred during the 1990s, including "identification in fabric and fruits, voice logging, wireless paging, and vehicle positioning."[425]

The Israeli military sector continues to show substantial spin-off effects, as the global defense market fails to offer adequate opportunities for export growth within the sector. A recent breakthrough idea that stemmed from defense innovation was, as noted, a swallowed medical diagnostics device based on missile technology. Another recent product spin-off was the robot

[424] De Fontenay and Carmel, "Israel's Silicon Wadi," 50.
[425] De Fontenay and Carmel, "Israel's Silicon Wadi," 50.

lawnmowers of Friendly Robotics, which were based on advanced missile-guidance technology for accurate positioning and navigation. Such examples exemplify the adaptation of defense technology by separate civilian businesses. Other examples involve adaptation by the defense industry itself, which has increasingly diversified into the civilian market, often by setting up civilian divisions. One such company is the Raphael Development Corporation (part of the Rafael Arms Development Authority), which develops military technologies for civilian use. The largest of Israel's defense companies, Israel Aerospace Industries, has long been a developer of commercial executive jets and a provider of upgrades for commercial aircraft, while Israel Military Industries has developed technology for electronic wallets and computerized payments systems.[426] The civilian content of new contracts in the Israeli defense industry—content, for example, exceeding 40 percent in IAI in 2000—remains significant.[427]

CONCLUSION

Israel currently stands as one of the world's most dynamic centers of entrepreneurship-led, ICT-related innovation and growth. Among the world's small number of high-tech clusters, Israel has the one that most closely resembles Silicon Valley, and in fact is widely seen as effectively an extension of Silicon Valley. High-tech start-ups form the backbone of the Israeli cluster, fueling the sector's prolific generation of R&D-based innovation. The start-up–intensive Israeli cluster has also spawned a financial community that invests in these start-ups and has intimate linkages with a broadening geographic base of foreign investors.

The innovative nature of the Israeli high-tech cluster has made it resilient, as demonstrated by its solid recovery from the global high-tech implosion and the resultant Israeli recession of 2001 to 2003. Also testifying to the cluster's resilience is the fact that Israel's security problems seem to have little impact on the viability of the high-tech sector, as measured by numerous indicators. Weathering both the high-tech implosion and security problems, Israel remains strongly innovative both in its continuing inventiveness within the cluster's still dominant ICT sector, and in the cluster's widening of its range of activities to emerging sectors, such as biotechnology, nanotechnology, and "cleantech."

[426] American-Israeli Cooperative Enterprise (AICE), "The Israeli Defense Industry."
[427] "Israel Military Guide: Military Industry," GlobalSecurity.org, n.d., http://www.globalsecurity.org/military/world/israel/index.html.

The resilience of the cluster is attributable in part to its very characteristics as a high-tech cluster. By definition, the presence of other, related competing and collaborating companies provides benefits for the individual companies, as do the service industries that the whole community of companies brings into being and strengthens. Israel's resilience as a cluster also likely stems from its reasonably wide diversification across high-tech industries. In principle, the benefits of cluster effects could be negated if the cluster were too narrowly specialized in industries that lost momentum. Israel has insured itself against this eventuality by broadening the scope of its high-tech pursuits. The technological composition of Israeli R&D and S&T activities reflects quite well worldwide technological growth trends, with ICT still dominant, but with life sciences industries increasing in importance. Within biotech, Israel is now a player roughly on a par with a number of mid-sized West European countries, such as Belgium. In the small field of stem-cell research, Israel is a world leader, and in certain water and solar technologies, the country maintains the headstart gained in "making the desert bloom."

The Israeli government plays a significant role in the Israeli cluster's diversification, just as it contributed to the cluster's emergence in the first place. The Israeli government periodically reaffirms the industrial policy first adopted in the late 1960s, in which R&D-based innovation in S&T in the business sector is assigned a central role in the economy and given various kinds of support. The government, chiefly, the Office of the Chief Scientist of the Ministry of Industry, Trade, and Labor, not only backs research programs but also positively encourages the development of start-up companies, allowing them to set the specific R&D agenda. In percentage terms, government financial support for innovation within new businesses has declined, as other sources of capital—thanks partly to government promotion—have grown. Such sources of capital include venture capital, foreign direct investment in mergers and acquisitions, and stock market offerings. Nonetheless, the government contributes in substantial ways to what can be termed renewal forces within the cluster. The government, for example, is active in setting up technology incubators specifically dedicated to promising fields, notably, biotechnology; in creating venues for academia–industry collaboration in fields such as nanotechnology and cleantech; and in fostering international R&D and S&T cooperation agreements across a widening array of countries.

Israel does face challenges, not the least of which is the perpetual security challenge, which periodically threatens to suppress outside business investment in Israel, and might even

erode Israel's attractiveness to skilled personnel as a place to locate permanently. Other challenges are maintaining the health of some of the factors that originally gave rise to Israel's high-tech cluster, particularly, the country's human capital assets. At the time of Israel's takeoff, it benefited from one unrepeatable windfall—the influx of ex-Soviet citizens—and the long-term investment the country had made in education and training of a skilled workforce. Maintaining the conditions for the continued flourishing of the high-tech cluster requires maintaining the investment in the academic system and the infrastructure of basic research. The Israeli government faces continual pressure to diminish such investments as it confronts demands for high military expenditures, combined with demands for the reduction of government expenditures—reductions that some see as necessary for competitiveness in a globalized world.

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In addition, the author consulted resources available on the following Web sites: Agricultural Research Organization of Israel (http://www.agri.gov.il); American–Israeli Cooperative Enterprise (AICE) (www.jewishvirtuallibrary.org); Army–Technology.com (http://www.army-technology.com); Artificial Intelligence and Robotics (http://smart-machines.blogspot.com); D&A Hi-Tech Information, Ltd. (http://www.dainfo.com); Elbit Systems (http://www.elbit.co.il); GlobalSecurity.org (http://www.globalsecurity.org); Hebrew University of Jerusalem (http://www.huji.ac.il); IBM Israel (http://www.haifa.ibm.com); IDE Technologies, Ltd. (http://www.ide-tech.com); Innovation Relay Centre Network–Israel (http://www.irc.org.il); Intel Corporation (http://www.intel.com); International Network of Engineers and Scientists Against Proliferation (http://www.inesap.org); Israel, Ministry of Agriculture and Rural Development, Office of the Chief Scientist (http://www.science.moag.gov.il); Israel, Ministry of Finance, International Affairs Department, OECD Coordinator (http://www.oecd.gov.il); Israel, Ministry of Foreign Affairs (http://www.mfa.gov.il); Israel, Ministry of Science, Culture, and Sport (http://www.most.gov); Israel Aircraft Industries (now Israel Aerospace Industries) (http://www/iai.co.il); Israel Association of Electronic and Information Industries (IAEI) (http://www.iaei.org.il); Israel Institute of Technology, Stephen and Nancy Grand Water Research Institute (http://gwri.technion.ac.il); Israel Military Industries (http://www.imi.co.il); Israel National Nanotechnology Initiative (INNI) (http://www.nanoisrael.org); Israel News Agency (http://www.israelnewsagency.com); Israel Oceanographic and Limnological Research (http://www.ocean.org.il); Israel Science Foundation (http://www.isf.org.il); Israel21c (www.israel21c.org); Israel Valley (www.israelvalley.com); Israel–Europe R&D Directorate for the EU Framework Program (ISERD) (www.iserd.org.il); Israeli Association of Software Houses (IASH) (http:www.iash.org.il); Israeli-Weapons.com (http://www.israeli-weapons.com); James Martin Center for Nonproliferation Studies (CNS) (http://www.cns.miis.edu); Nano Functional Materials (http://www.nfm.org.il); Nemesysco, Ltd. (http://www.nemesysco.com); and Raphael Advanced Defense Systems Ltd. (http://www.rafael.co.il).